Rare Kaon Decays: Extreme Physics with Extreme Beams

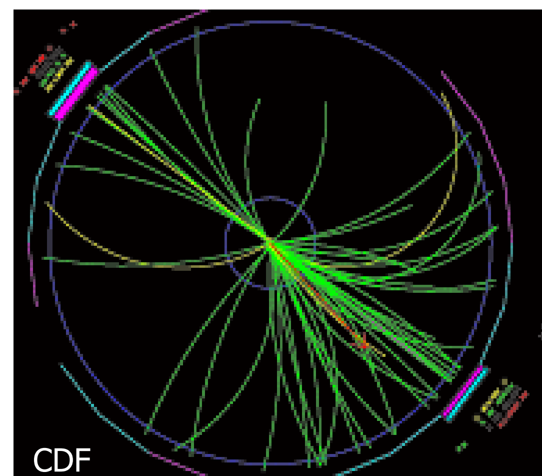
Augusto Ceccucci/CERN

Fermilab, August 20, 2009

The success of the SM

- **The SM has been proven to be extremely successful since 1970's**
  - Simplicity (6 quarks explain >40 mesons and baryons)
  - Explains all interactions in current accelerator particle physics
  - Predicted many particles (most prominent *W*, *Z*)
- **Limitations of the SM**
  - Currently contains 19 free parameters such as the particle masses
  - Does not explain cosmological observation such as Dark Matter and Matter/Antimatter As
  - EW
  (M
  - Stability of Higgs mechanism

Today's goal is to look for physics beyond the Standard Model



Extreme Physics

- **There are three main directions in particle physics to crack the Standard Model**
  - Energy Frontier (Tevatron, LHC, ILC/CLIC,..)
  - Rarity (Intensity) Frontier
  - Astroparticle
- **At the Rarity Frontier**
  - Neutrinos (θ_{13}, CPV, Majorana mass,…)
  - Charged Leptons (g-2, $\mu \rightarrow e\,\gamma$; $\mu \rightarrow e$)
  - Mesons ($K \rightarrow \pi\nu\nu$, $B \rightarrow \tau\,\nu$, $B \rightarrow \mu\mu$,…)

Flavor Problem:
Lack of Indirect New Physics Effects

Any FT can be viewed as an effective theory below a UV cutoff

$$L_{eff} = L^{d=4}(g,\lambda) + \frac{1}{\Lambda} L^{d=5} + \frac{1}{\Lambda^2} L^{d=6} + \ldots$$

g gauge

λ Yukawa

Λ has physical meaning: maximum energy at which the theory is valid. Beyond Λ, new degrees of freedom

Higgs naturalness gives an upper bound on Λ~O(TeV), BUT:

Adapted from G. Giudice

B number $\Rightarrow \frac{1}{\Lambda^2} qqql$ p-decay $\Rightarrow \Lambda \geq 10^{15}$ GeV

L number $\Rightarrow \frac{1}{\Lambda} l\, lHH$ ν mass $\Rightarrow \Lambda \geq 10^{13}$ GeV

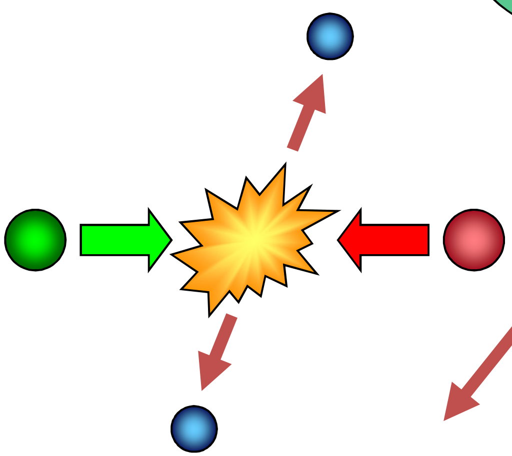
individual L $\Rightarrow \frac{1}{\Lambda^2} \bar{e} \sigma^{\mu\nu} \mu H F_{\mu\nu}$ $\mu \to e\gamma \Rightarrow \Lambda \geq 10^{8}$ GeV

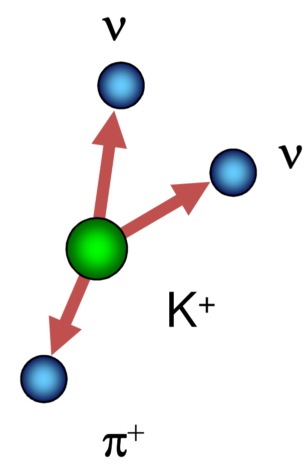
quark flavour $\Rightarrow \frac{1}{\Lambda^2} \bar{s} \gamma^{\mu} d\, \bar{s} \gamma_{\mu} d$ $\Delta m_K \Rightarrow \Lambda \geq 10^{6}$ GeV

LEP1,2 $\Rightarrow \frac{1}{\Lambda^2} \left| H^{+} D_{\mu} H \right|^2, \ \frac{1}{\Lambda^2} \bar{e} \gamma^{\mu} e\, \bar{l} \gamma_{\mu} l$ $\Rightarrow \Lambda \geq 10^{4}$ GeV

Experimental Techniques

Search for New Physics Beyond the SM





Energy Frontier

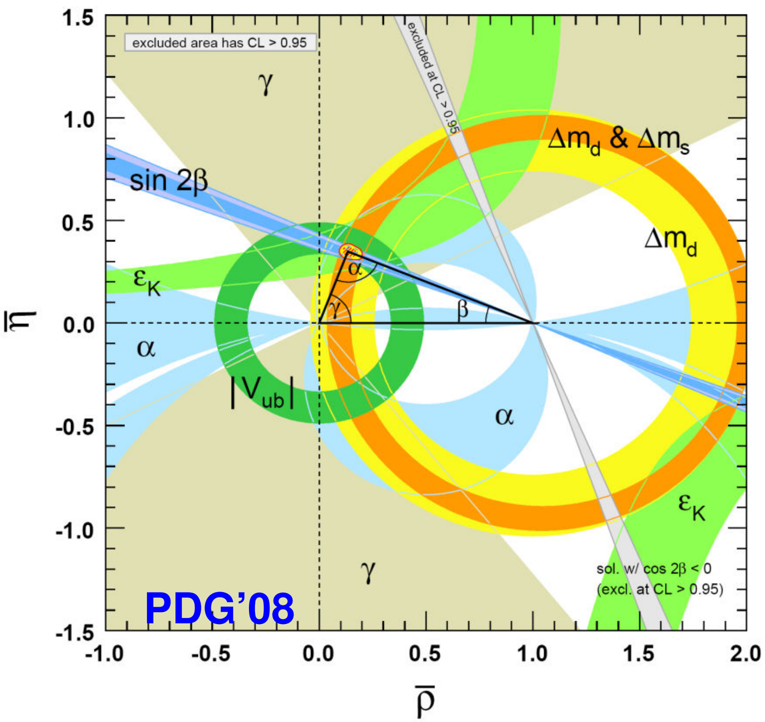
- Produce heavy new particles directly
- Heavy particles need large colliders
- Complex detectors

Rarity Frontier

- Look for deviations from precise SM predictions, CKM, K, B Decays
- Look for rare or forbidden processes
- Requires high precision & intensity

Flavor in the Era of the LHC*

- **The current experimental manifestations of CP-Violation (K and B decays and mixing) are consistent with "just" one complex phase in the CKM matrix ("Standard Model")**



***CERN Extended workshop, Nov 2005, March 2007, Edited by R. Fleischer, T. Hurth and M.L. Mangano**
EPJ C, 57, Vol 1-2, Sept 2008

"[These articles] confirm that flavour physics is an essential ingredient in the future of high-energy physics"

- **Paradigm shift: we should determine the "true" CKM parameters from observables not affected by New Physics (e.g. B tree decays) and measure loop-induced, precisely predictable (SM), FCNC to detect patterns of deviation**

Isidori's FCNC Matrix

	b → s (~λ^2)	b → d (~λ^3)	s → d (~λ^5)
ΔF=2 Box	Λ > 100 TeV from ΔM_{Bs} $A_{CP}(B_{ds} \to \psi\phi)$	Λ > 2x10^3 TeV from $A_{CP}(B_d \to \psi K)$	Λ > 2x10^4 TeV from ε_K
ΔF=1 4-quark Box			
Gluon Penguin	Λ > 80 TeV from B($B \to X_s\gamma$)		Λ > 10^3 TeV from $\varepsilon'/\varepsilon_K$
γ Penguin	Λ > 150 TeV from B($B \to X_s\gamma$)		
Z^0 Penguin	Λ > 20 TeV From B($B \to X_s \ell^+\ell^-$)		B($K \to \pi \nu\nu$) B($K_L \to \pi \ell^+\ell^-$)
H^0 Penguin	B($B_s \to \mu\mu$)	B($B_d \to \mu\mu$)	

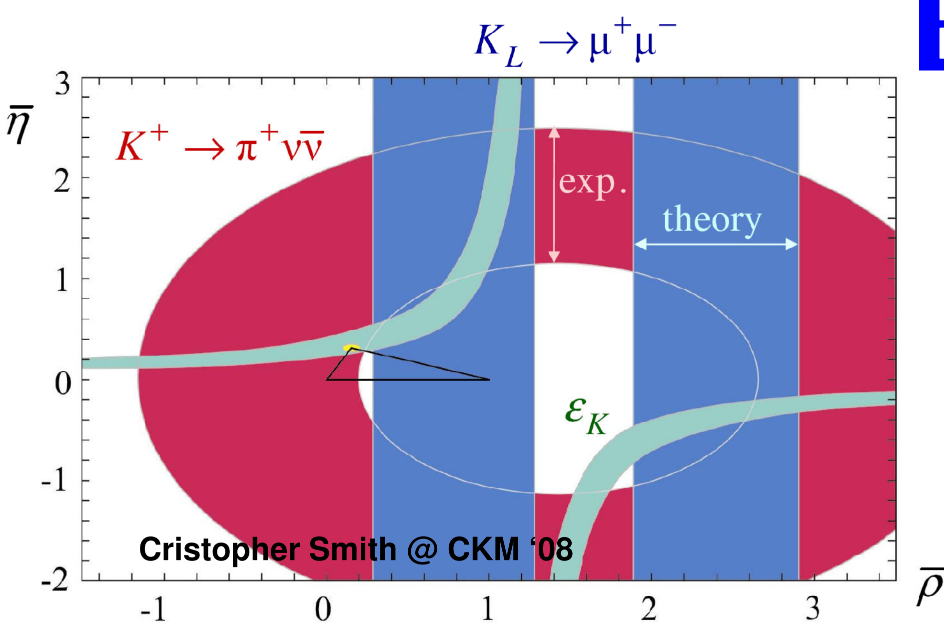
Present Bounds on Λ assuming O(1) Flavor-changing couplings

Corners where Sizable Non-standard Effects could hide

$K \to \pi\nu\bar{\nu}$: Theoretically Pristine

Decay	Branching Ratio ($\times 10^{10}$) Theory (SM)	Experiment
$K^+ \to \pi^+\nu\bar{\nu}(\gamma)$	0.85 ± 0.07 [1]	$1.73^{+1.15}_{-1.05}$ [2]
$K_L^0 \to \pi^0\nu\bar{\nu}$	0.26 ± 0.04 [3]	< 670 (90% CL) [4]

[1] J.Brod, M.Gorbahn, PRD78, arXiv:0805.4119
[2] AGS-E787/E949 PRL101, arXiv:0808.2459
[3] M. Gorbahn
[4] KEK-E391a PRL 100, arXiv:0712.4164



$K_L \to \pi^0\nu\bar{\nu}$: $\bar{\eta} < 17$ — **E391a**

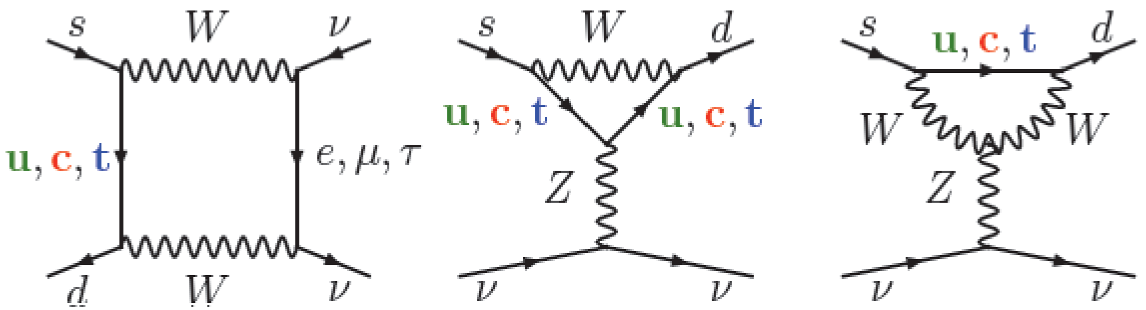
$K_L \to \pi^0 e^+ e^-$: $\bar{\eta} < 3.3$

$K_L \to \pi^0 \mu^+\mu^-$: $\bar{\eta} < 5.4$

KTeV

SM Prediction: $K^0_L \to \pi^0 \nu\bar{\nu}$

- **One Dominant Operator:** $Q_\nu = (\bar{s}_L \gamma_\mu d_L)(\bar{\nu}_L \gamma^\mu \nu_L)$

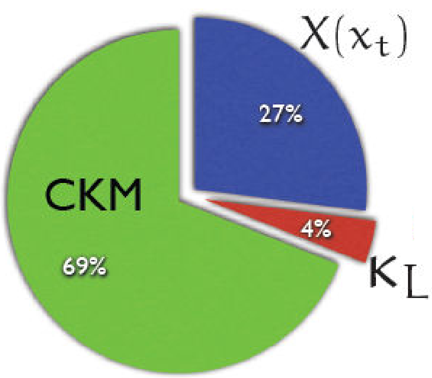


- **Only top quark contributes** $H_{eff} = \frac{4G_F}{\sqrt{2}} \frac{\alpha V^*_{ts} V_{td}}{2\pi \sin^2 \Theta_W} X(\chi_t) Q_\nu$

- **Use isospin symmetry to normalise to $K^+ \to \pi^0 e^+ \nu$**

$$Br(K^0_L \to \pi^0 \nu\bar{\nu}) = \kappa_L \left(\frac{\mathrm{Im}(V^*_{ts} V_{td})}{\lambda^5} X(\chi_t) \right)^2 = (2.6 \pm 0.4) \times 10^{-11}$$

λ= Cabibbo Angle

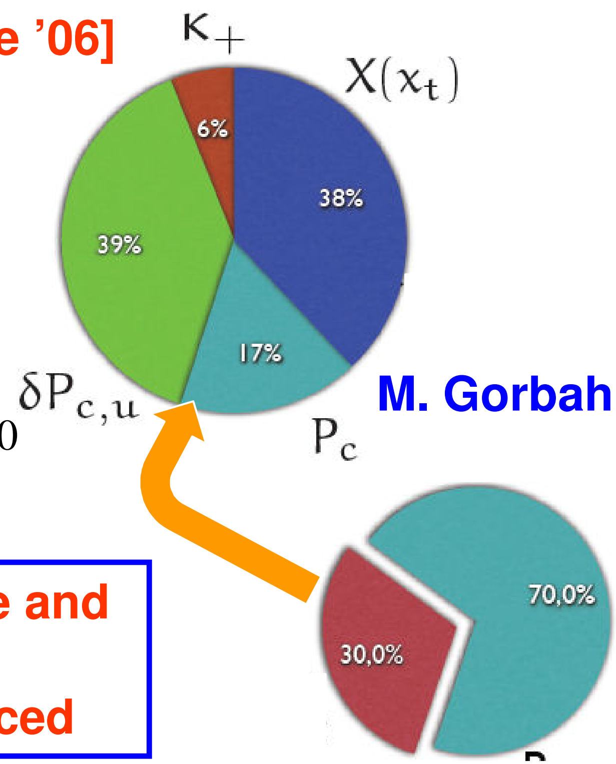


- **Error of parametric origin**

SM Prediction: $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

$$B(K^+ \to \pi^+ \nu\bar{\nu}(\gamma)) = k_+ (1+\Delta_{EM}) \times \frac{|V_{ts}^* V_{td} X_t(m_t^2) + \lambda^4 \,\mathrm{Re}\, V_{cs}^* V_{cd} (P_c(m_c^2) + \delta P_{c,u})|^2}{\lambda^5}$$

- NLO QCD [Buchalla, Buras '94], [Misiak, Urban '99], [Buchalla, Buras '99]
- Charm
  - NNLO QCD[Buras, Gorbahn, Haisch, Nierste '06]
  - EW Corrections to P_c [Brod, Gorbahn '08]
- Long Distance
  - $|\Delta E| < 1\%$ [Mescia, Smith '07]
  - $\delta P_{c,u}$ +6% [Isidori, Mescia, Smith '05]



M. Gorbahn

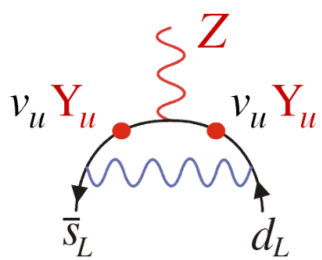
$$Br(K^+ \to \pi^+ \nu\bar{\nu}(\gamma)) = (0.85 \pm 0.07) \times 10^{-10}$$

- The SM Branching Ratio prediction is precise and the intrinsic theory error is small
- The parametric error (70%) will be further reduced

Kaon Rare Decays and NP

(courtesy of Christopher Smith)

C. The Z penguin (and its associated W box)

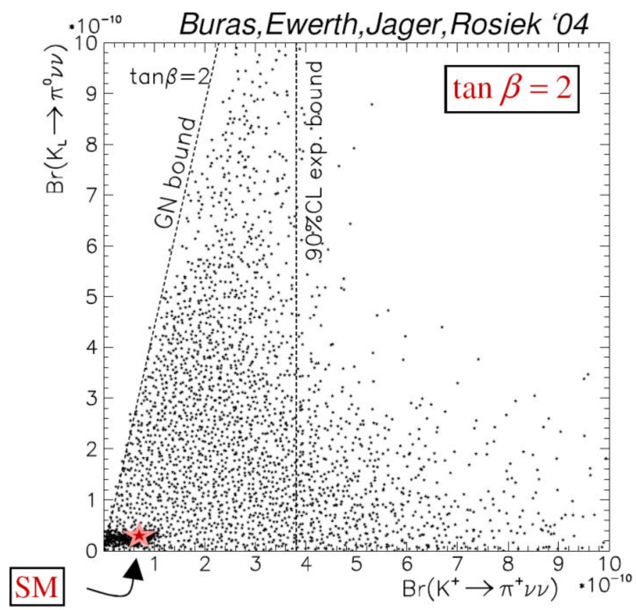


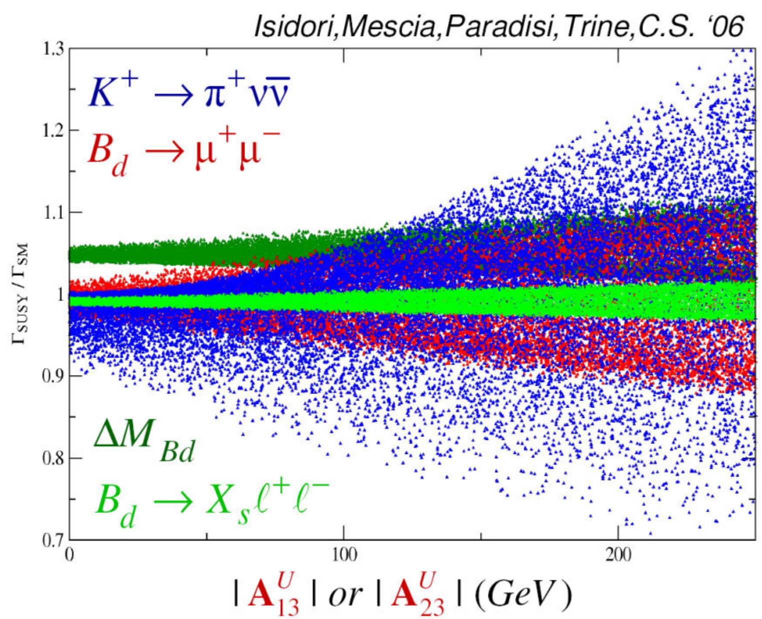
- $SU(2)_L$ breaking: $SM : v_u^2 \mathrm{Y}_u^{*32} \mathrm{Y}_u^{31} \sim m_t^2 V_{ts}^* V_{td}$

$$MSSM : v_u^2 \mathrm{A}_{\tilde{u}}^{*32} \mathrm{A}_{\tilde{u}}^{31} \sim m_t^2 \times O(1)\,?$$

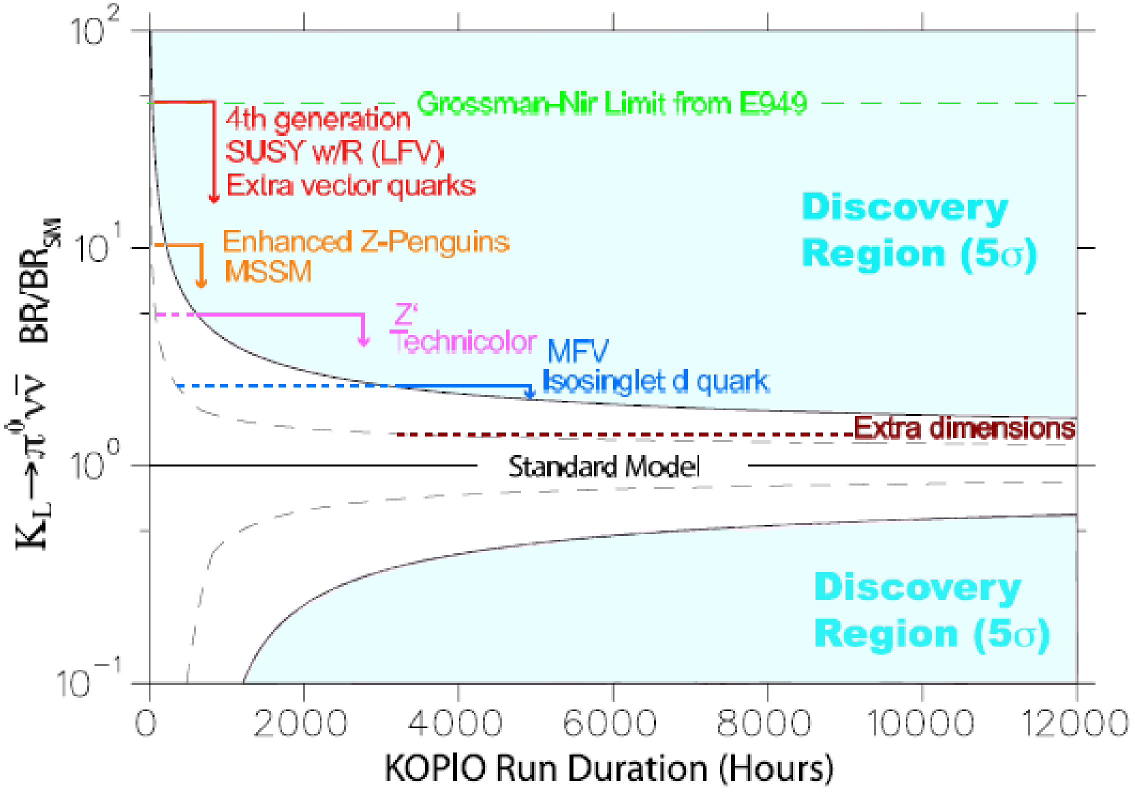
$$MFV : v_u^2 \mathrm{A}_{\tilde{u}}^{*32} \mathrm{A}_{\tilde{u}}^{31} \sim m_t^2 V_{ts}^* V_{td} \left| A_0 a_2^* - \cot\beta\mu \right|^2 .$$

- Relatively slow decoupling (w.r.t. boxes or tree).





Physics Reach



D. Bryman, A. Buras, G. Isidori, L. Littenberg, Int.J.Mod.Phys.A21:487-504,2006.
e-Print: **hep-ph/0505171**

Extreme Physics

- The physics is compelling
- A strong experimental effort has taken place over many years: many original ideas were born at Fermilab
- In my opinion, dedicated and ingenuous experiments are justified by the physics case and required for decisive progress
- To study precisely Branching Ratios of 10^{-10} or smaller very intense, “extreme”, sources of Kaons are required
- And such Kaon sources require large proton complex (BNL, FNAL, CERN, JPARC,…)

Neutral Beams for $K^0_L \rightarrow \pi^0 \nu\bar{\nu}$

"Pencil"

- π^0 + "nothing"
- P_T cut for $\Lambda \rightarrow n\pi^0$ & $K^0_L \rightarrow 2\pi^0$ suppression
- hermetic calorimetry

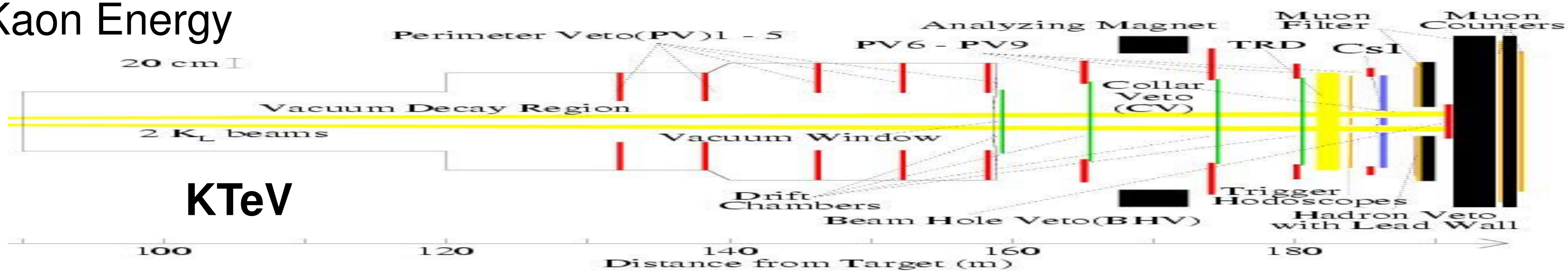
"Microbunched"

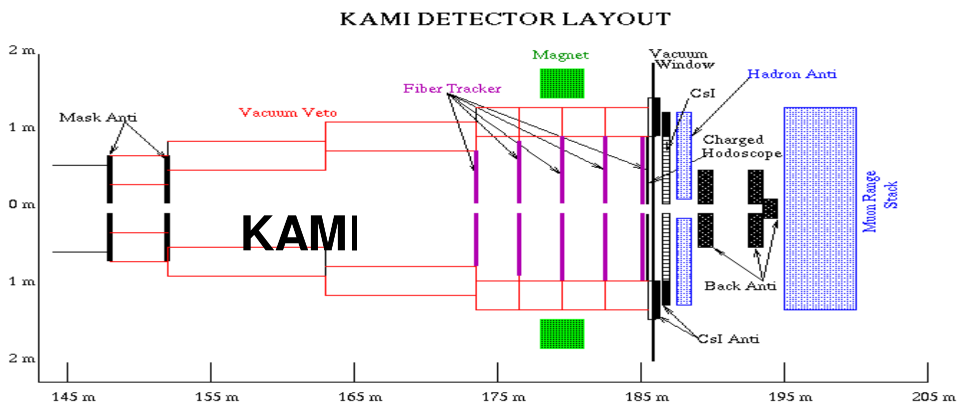
- E_K from TOF
- Low(er) Kaon Energy
- KOPIO BNL Concept further elaborated for FNAL (Bryman@KAON09)

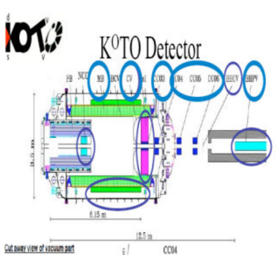
Exp	Machine	Status	UL 90% CL	Notes
KTeV	Tevatron	CO	$< 5.7 \times 10^{-7}$ ($\pi^0 \rightarrow ee\gamma$)	
KAMI	MI	PR		Discussed in 2001
KOPIO	AGS	PR		Opportunity at FNAL?
E391a	KEK-PS	AN	$< 6.8 \times 10^{-8}$	
KOTO	J-PARC MR	AP		Aim at 2.7 SM evts / 3 y
KLOD	U70	PR		

K^0_L Pencil: E_K vs Length

Increasing Kaon Energy



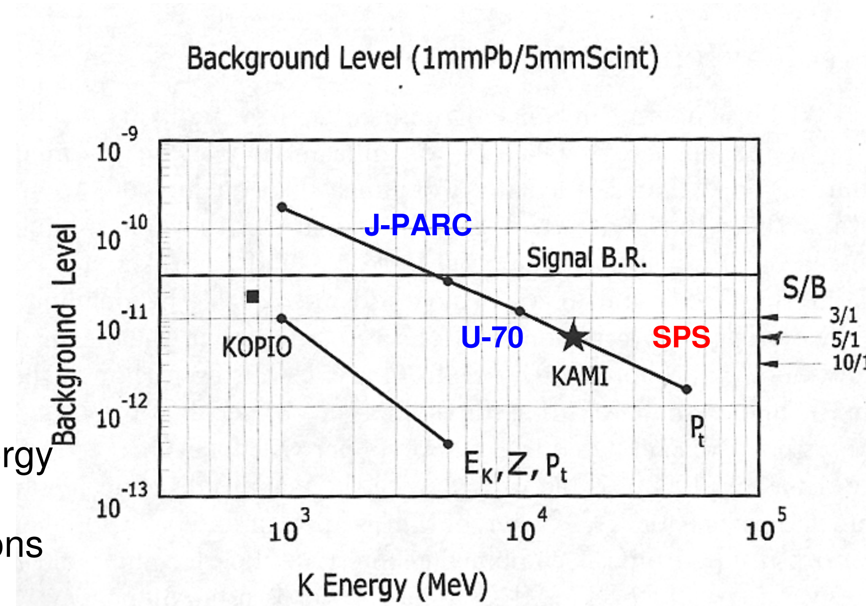




KOTO

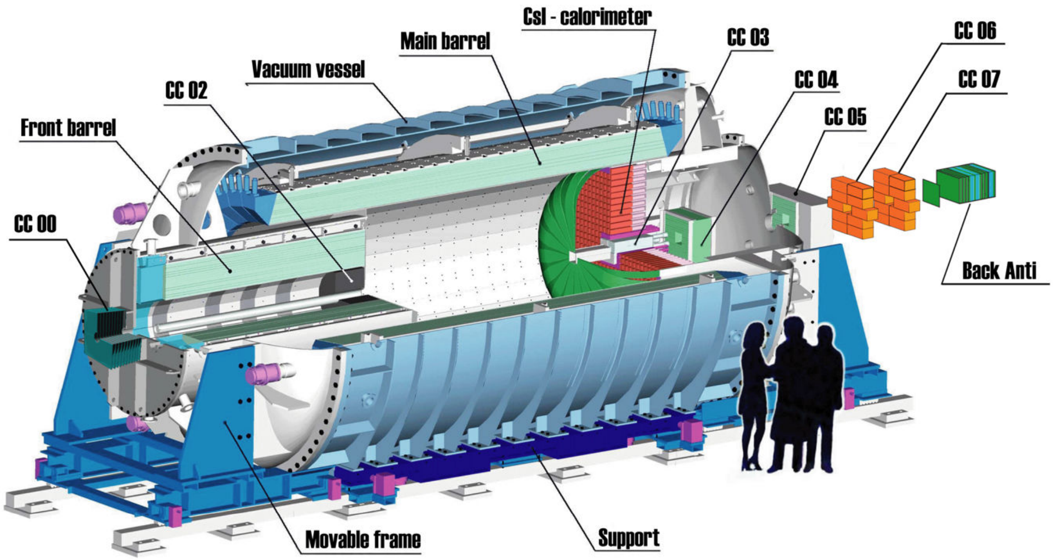
Trade-off between higher Kaon Energy for better background suppression and (longitudinal) detector dimensions

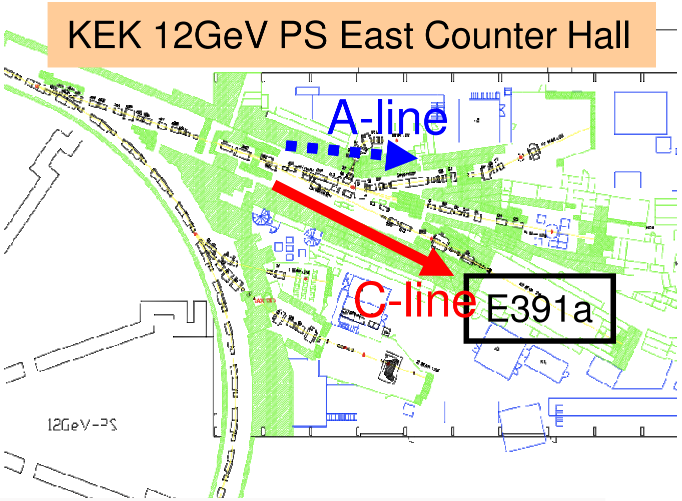
(c.f. KAMI proposal)

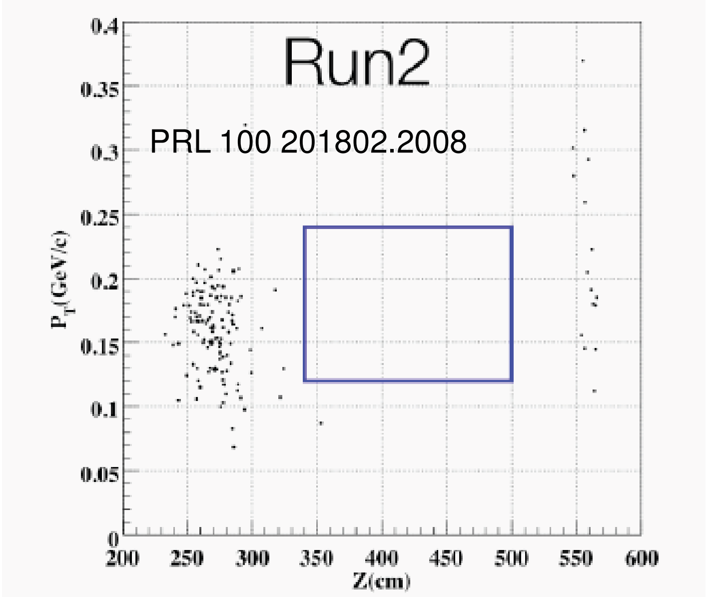


Experiment Length

E391a @ KEK PS







Run I: Feb - Jul 2004

Run II: Feb - April 2005 (1.4×10^{18} POT)

$B(K^0_L \rightarrow \pi^0 \nu\bar{\nu}) < 6.7\ 10^{-8}$ 90% CL

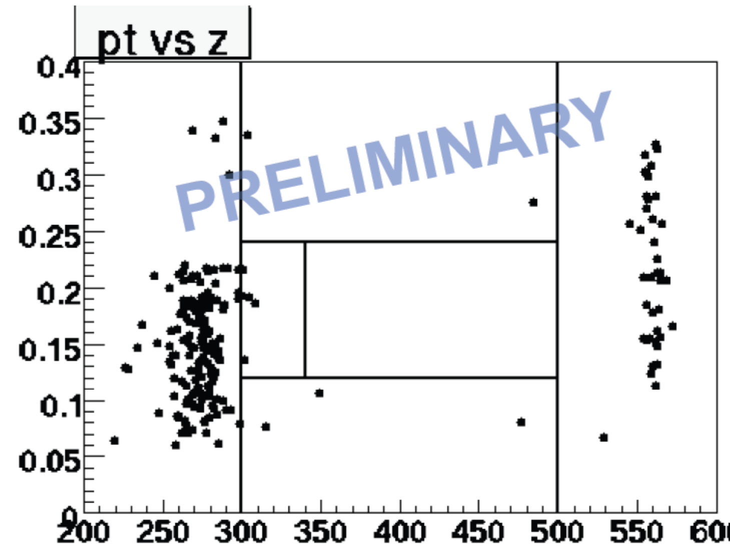
Run III: Nov - Dec 2005 (~70 % of Run II)

Added “Back Anti” and Aerogel γ counter

E391a Run III

Acceptance 0.975%
Flux 3.48 x 10^9 K^0_L

- **Prel. Result from Run III presented by Hideki Morii at KAON09**
- **Systematic Study of the backgrounds induced by the halo neutrons**
- **Improved acceptance by ~2 for the similar S/N**
- **Run II, Run III combination underway**
- **Possible reanalysis of Run II**



$B(K^0_L \rightarrow \pi^0 \nu\bar{\nu}) < 6.8\ 10^{-8}$ 90% CL

K^0_L Background	$\pi^0\pi^0$	**0.14**
	$e^+\pi^-\nu$	**0.0047**
Halo Neutrons		**0.29**

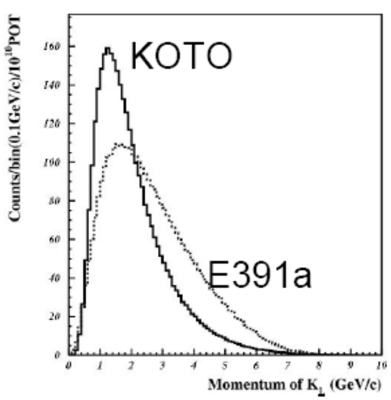
KOTO (E14) @ JPARC

Aim for **Flux x Run Time x Acceptance = 3000 x E391a**

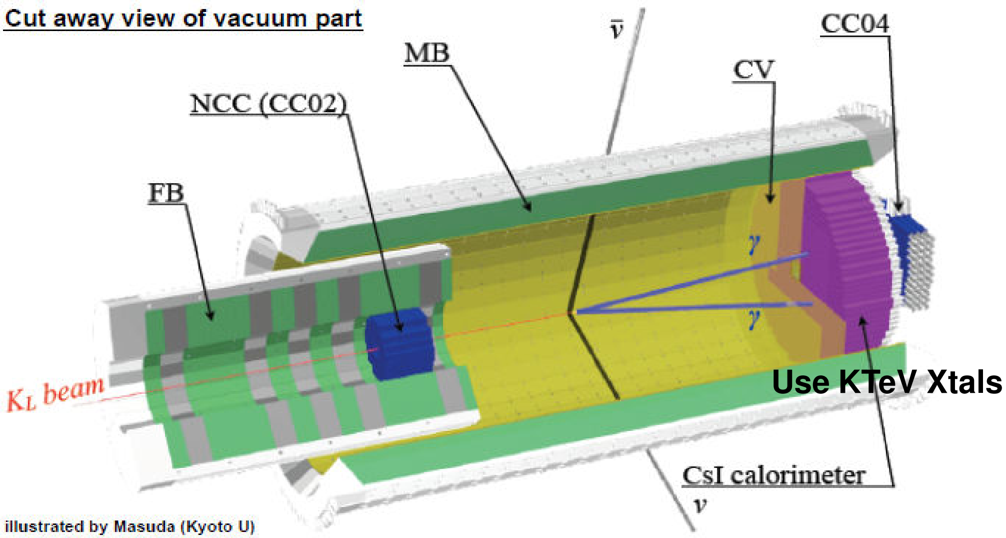
	KOTO	E391a (Run2)	
Proton energy	30 GeV	12 GeV	
Proton intensity	2e14	2.5e12	
Spill/cycle	0.7/3.3sec	2/4sec	
Extraction Angle	16 deg	4 deg	
Solid Angle	9μStr	12.6μStr	
KL yield/spill	7.8e6	3.3e5	x30 /sec
Run Time	3 Snowmass years =12 months.	1 month	x10
Decay Prob.	4%	2%	x 2
Acceptance	3.6%* *without Back splash loss	0.67%	x5

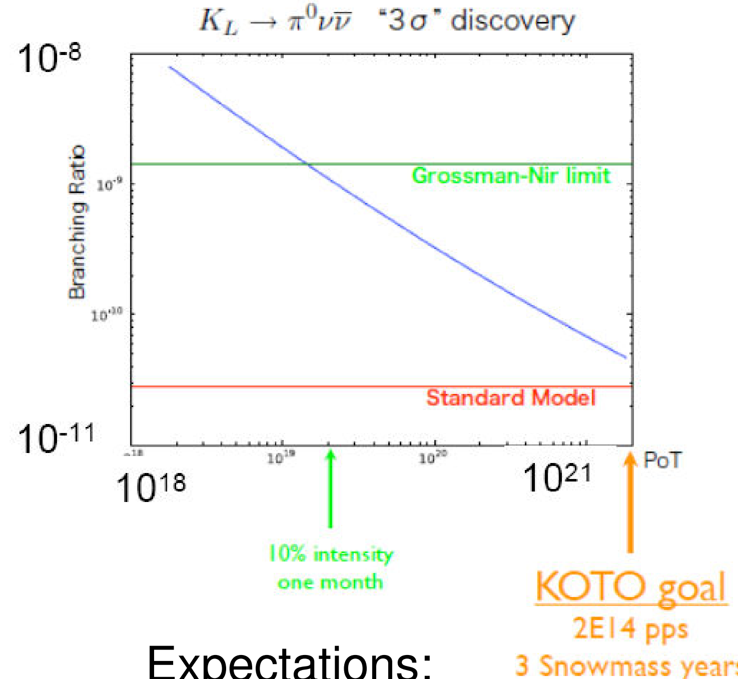
Main Ring Parameters:
L=1.6 Km
30 GeV
2 x 10^{14} ppp
0.3 MW
0.7 s spill / 3.3 s

Details in H. Nanjo KAON'09



KOTO @ JPARC





Schedule (H. Nanjo, KAON2009)

2009

- Beamline construction
- Beam Survey

2010

- CsI Calorimeter Construction
- Engineering run with CsI calorimeter

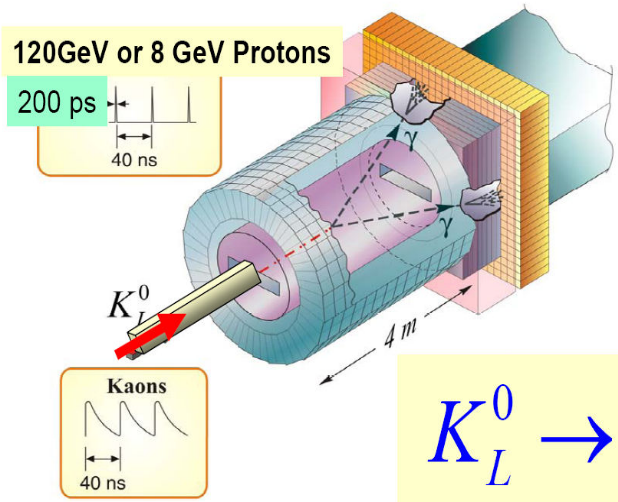
2011

- Physics Run start

Expectations:

Signal	$K^0_L \to \pi^0 \nu\nu$	2.7
K^0_L Background	$\pi^0\pi^0$	1.7
	$\pi^+\pi^-\pi^0$	0.08
	$e^+\pi^- \nu$	0.02
Halo Neutrons		0.38

K^0_L @ FNAL ?



$$K^0_L \to \pi^0 \nu \bar{\nu}$$

$$K^0_L \to \pi^0 \nu \bar{\nu}$$

D. Bryman @ KAON09

High intensity of Project X is ideal for the TOF-based K_L experiment.

- Small aperture, symmetric beam - makes for simpler, higher acceptance detector
- Exploit advances in instrumentation

- 300 events/year at 1st stage of Project X; 3% precision possible after 5 years.
- 5 times higher intensity could be used to get ~900 events/year
- **Similar possibilities may be available with the MI+Tevatron Stretcher approach**

- TOF to determine Kaon Energy
- Knowledge of E_K allows rejection of two body decays
- Pointing Calorimeter
- 4 π veto for neutral and charged particles
- Small Beam instead of flat beam

Charged Beams for $K^+ \to \pi^+ \nu\bar{\nu}$

"Stopped"

- Work in Kaon frame
- High Kaon purity (Electro-Magneto-static Separators)
- Compact Detectors

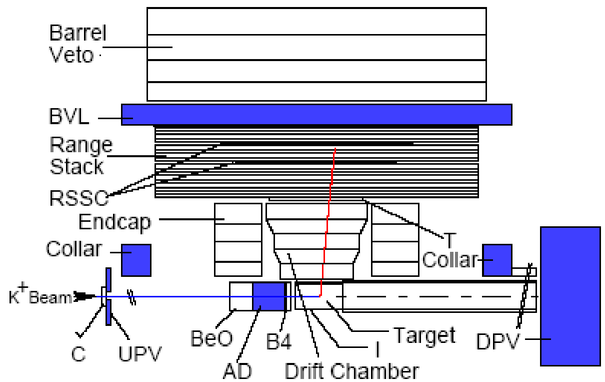
"In-Flight"

- Decays in vacuum (no scattering, no interactions)
- RF separated or Unseparated beams
- Extended decay regions

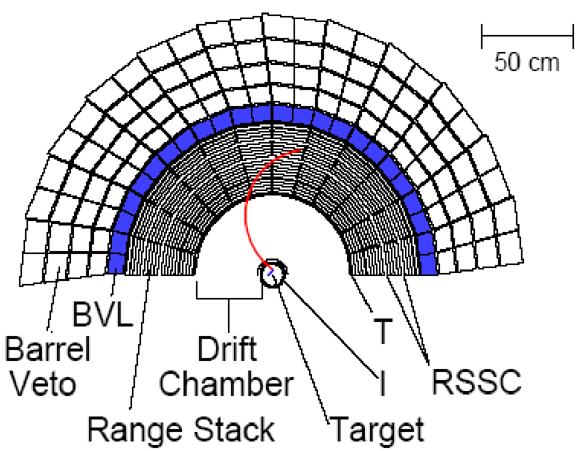
Exp	Machine	Status	Meas. or UL 90% CL	Notes
	Argonne	CO	$< 5.7 \times 10^{-5}$	Stopped; HL Bubble Chamber
	Bevatron	CO	$< 5.6 \times 10^{-7}$	Stopped; Spark Chambers
	KEK	CO	$<1.4 \times 10^{-7}$	Stopped; $\pi^+ \to \mu^+ \to e^+$
E787	AGS	CO	$(1.57^{+1.75}_{-0.82}) \times 10^{-10}$	Stopped
E949	AGS	CO	$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$	Stopped; PPN1+PPN2
CKM	MI	CA		In-Flight; Separated; RICH vel. sp.
NA62	SPS	AP		In-Flight; Unseparated

E787/E949: "Extreme Beam"

"The entire AGS beam of 65 x 10^{12} (Tp/ spill) at a momentum of 21.5 GeV/c was delivered to the E949 K^+ production target"



- Duty Factor: 2.2 s / 5.4 s ~ **40%**
- 1 int. length Pt target
- Before separators: 500 π : 500 p : 1 K
- After separators: Purity **K:π ~ 3-4 : 1**
- Incoming **710 MeV/c** K^+ identified by Č and slowed down by BeO and Active Degrader
- **~27%** K^+ stopped in the target (1.6 MHz)
- 1 T solenoid

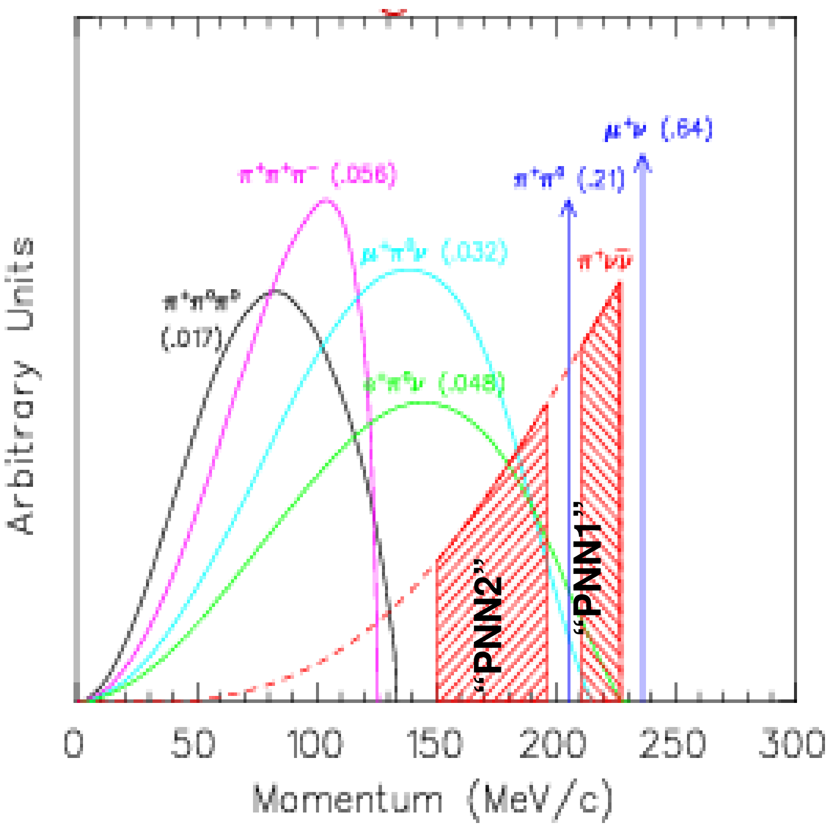


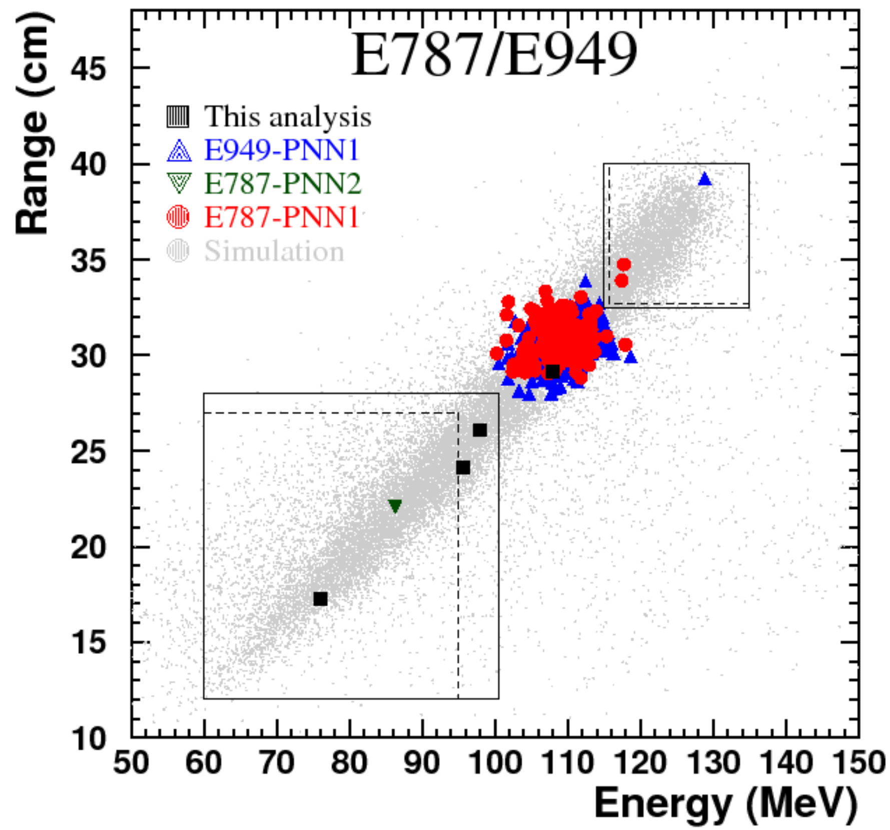
K^+: Č x B4 x Target

π^+: Delayed Coincidence
Range
Energy
Momentum
$\pi^+ \rightarrow \mu^+ \rightarrow e^+$

E787/E949: "Etreme Physics"

Presented by Ilektra A. Christidi @"New Opportunities in Kaon Physics" Birmingham, UK, Nov 27, 2008





$$B(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$$

Stopped Kaon Redux?

Can one improve significantly over the E949 PNN1 efficiency figures?

Selection	α	Notes
$K\mu 2$	0.38	Beam,T, RS rec.
$K\pi 2$	0.88	E, range, selection
Pscat	**0.62**	Rej. of beam scat.
$\pi \rightarrow \mu \rightarrow e$	**0.35**	Decay chain
Trig	**0.18**	Trigger eff.
PS	**0.36**	Phase Space
nucl.	**0.50**	Pion interaction
T2	0.94	topology
fs	**0.77**	Stopping Fraction
"Standard"	1.7×10^{-3}	Total efficiency

- "Only" ~22% (.77 x .28) of kaons stopped in target
- The product of the red factors (1.5×10^{-2}) Is a high price to pay: $1/(1.5 \times 10^{-2}) \sim$ **66x**

Possible Improvements (Bryman@KAON09):

1. Lower Kaon Momentum to increase the stopped kaon fraction
2. Larger Beam acceptance

→ **4-5x**

3. Detector Improvement: finer RS segmentation; LXe γ veto

→ **> 5x**

Stopped Kaon @ FNAL?

D. Bryman @ KAON09

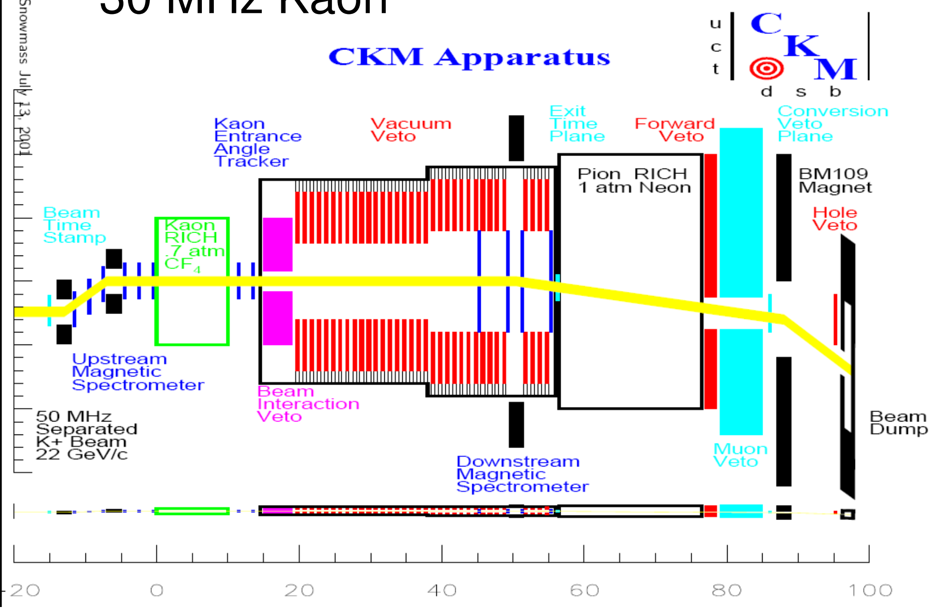
$K^+ \to \pi^+ \nu \bar{\nu}$	FNAL "Booster" (20 kW)	FNAL Tevatron Stretcher 12%MI	FNAL Project-X
Events/yr*	40	200	325
Events/5yr	200	1000	1600
Precision**	**8**	**3.6**	**3**

**Estimates based on extrapolation of BNL E949.*

*** Includes separate estimates of backgrounds in Regions I (10%) and 2 (75%).*

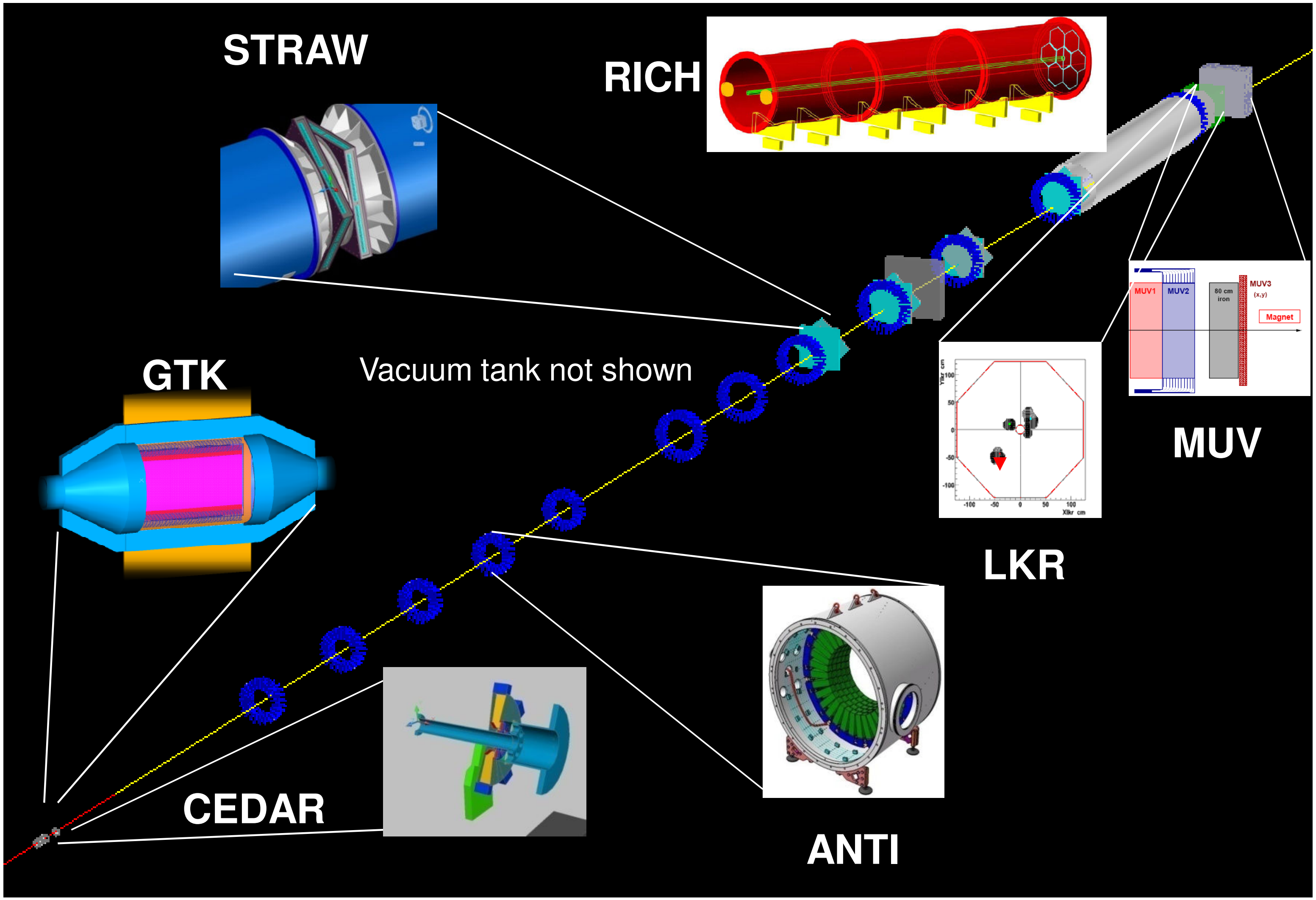
CKM Proposal

"Extreme" RF Separated beam
MI protons (120 GeV)
5 x 10^{12} protons / s
30 MHz Kaon



- **RICH Velocity Spectrometer**
- **Full redundancy: magnetic vs. velocity Spectrometers**
- **Approved but not built**
- **Inspiration for NA62 RICH & STRAW**

NA62 @ CERN-SPS



Protons / Useful Kaon & Purity

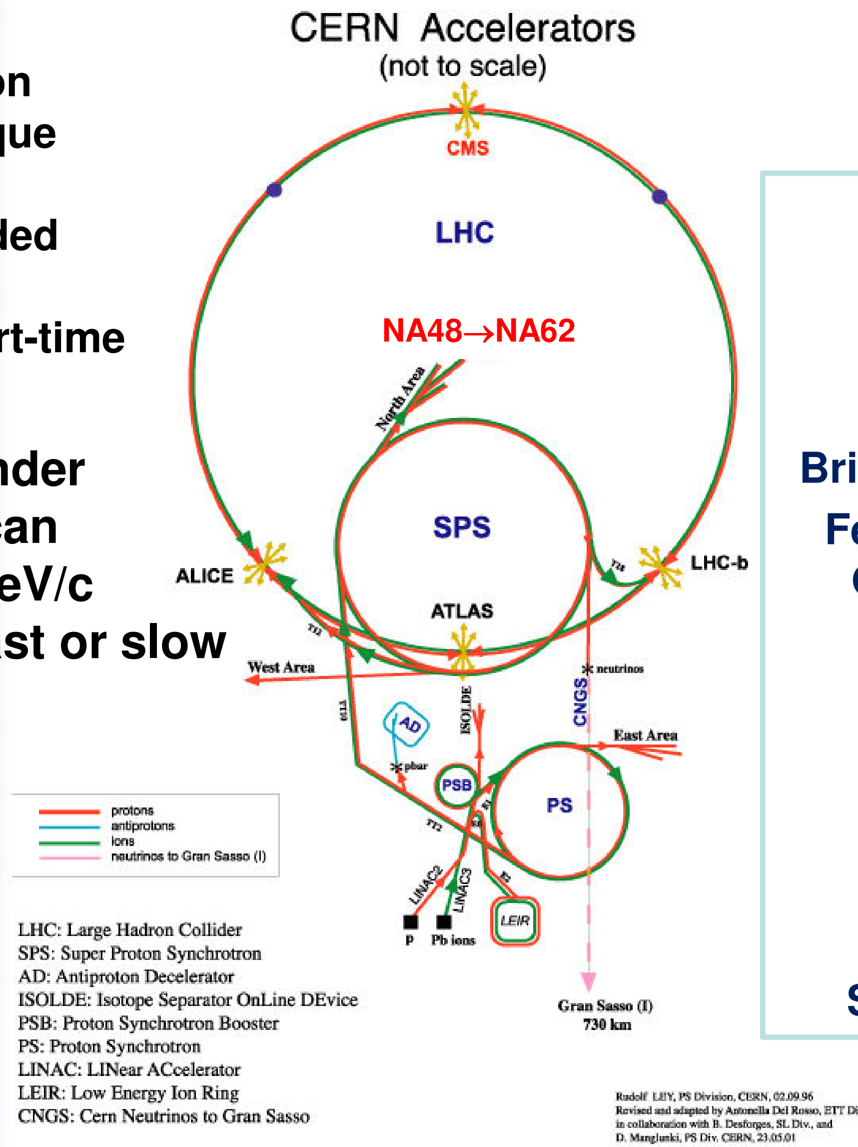
	P0 (GeV)	Proton / s	K (MHz)	Decays (MHz)	Duty Factor	Decays / 200 d	p/ K decay (105)
E949	21.5	$3\ 10^{13}$	6.5	1.3	0.41	$1.4\ \ 10^{13}$	210
CKM	120	$5\ 10^{12}$	30	5.1	0.33	$2.9\ \ 10^{13}$	10
NA62	400	$1\ 10^{12}$	45	4.5	0.30	$2.3\ \ 10^{13}$	2.2

	K	π	p	K%
E949	3-4	1	--	~75
CKM	2	1	--	~60
NA62	1	12	4	~6

The CERN proton Complex is unique

The SPS is needed as LHC proton injector only part-time

For the remainder of the time it can provide 400 GeV/c protons for fast or slow extraction



NA62:

Bern ITP, Birmingham,
Bristol, CERN, Dubna,Fairfax,
Ferrara, Florence, Frascati,
Glasgow, IHEP Protvino,
INR Moscow,
Liverpool, Louvain,
Mainz, Merced, Naples,
Perugia, Pisa,
Rome I, Rome II,
San Luis Potosí,
SLAC,Sofia,TRIUMF,Turin

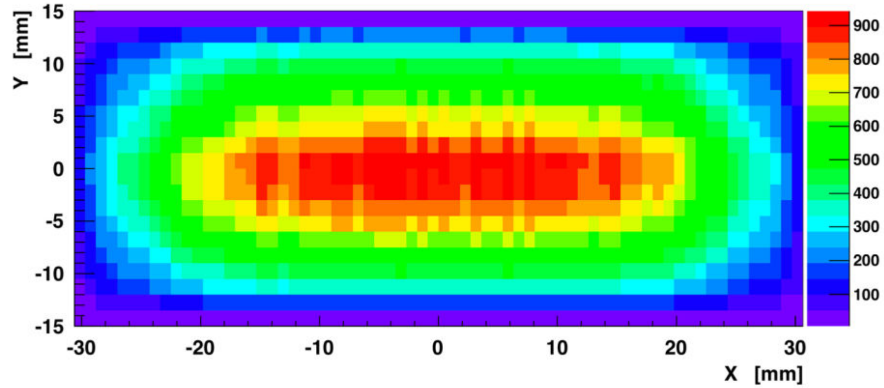
Principles of NA62

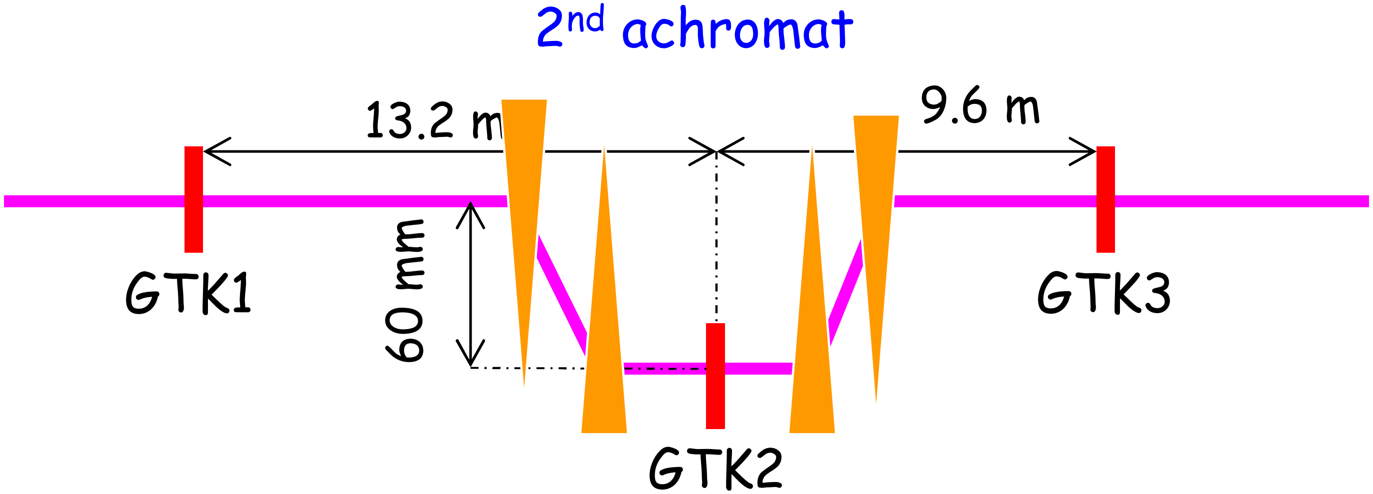
- **K+ Decay in-flight** to avoid the scattering and the backgrounds introduced by the stopping target
  → long decay region
- **High momentum** to improve the background rejection
  → unseparated hadron beam

1. **Precise timing** to associate the decay to the correct incoming parent particle (K^+) in a ~800 MHz beam
   → Beam tracker with σ_t~100 (GTK)
2. **Kinematical Rejection**
   → low mass tracking (GTK + STRAW in vacuum tank)
3. **Vetoes (γ and μ)**
   → ANTI (OPAL lead glass) + NA48 LKR
   → MUV
4. **Particle Identification**
   → K/π (CEDAR)
   → π/μ (RICH)

NA62 “Extreme” Beam ....

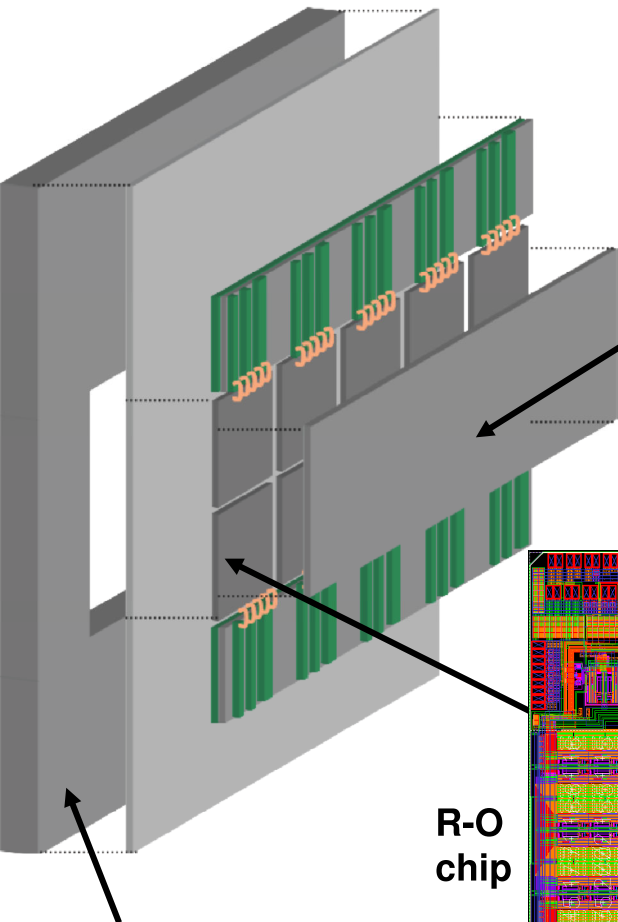
SPS primary p: 400 GeV/c
Unsepared beam:
- **75 GeV/c**
- **750 MHz**
- **π/K/p (~6% K^+)**

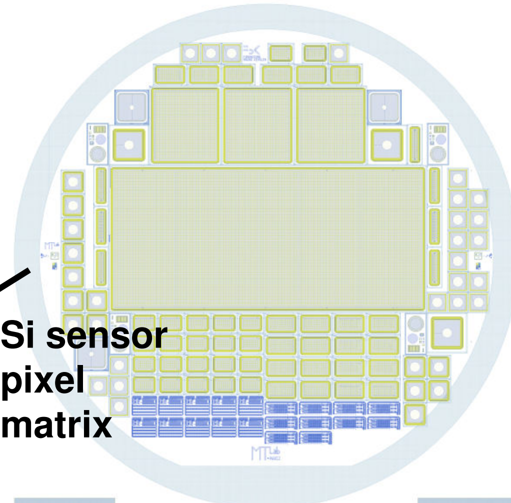


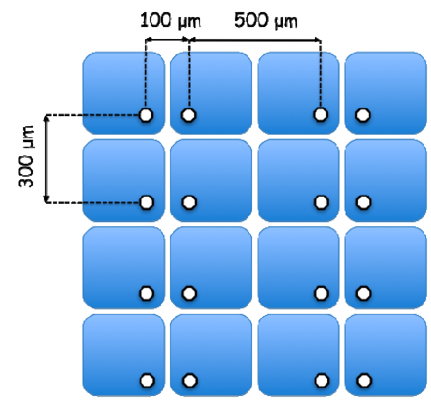


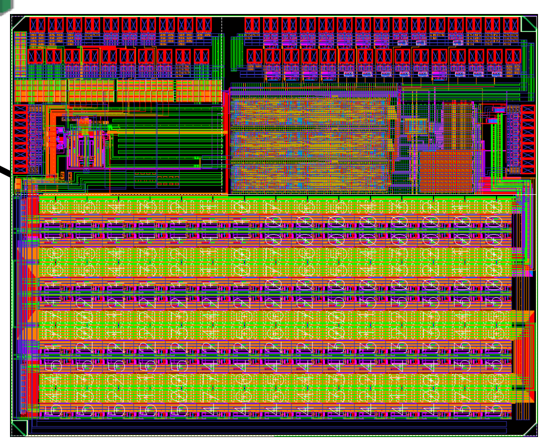
- **Sensitivity is NOT limited by protons flux but by beam (Giga)tracker (GTK)**
- **Similar amount of protons on target as NA48 (~5 10^{12} / pulse)**

…and NA62 “Extreme” Tracker









Requirements:

Track and time each beam particle

Time resolution: 200 ps / station

Material Budget: < 0.5 % X_0 /station

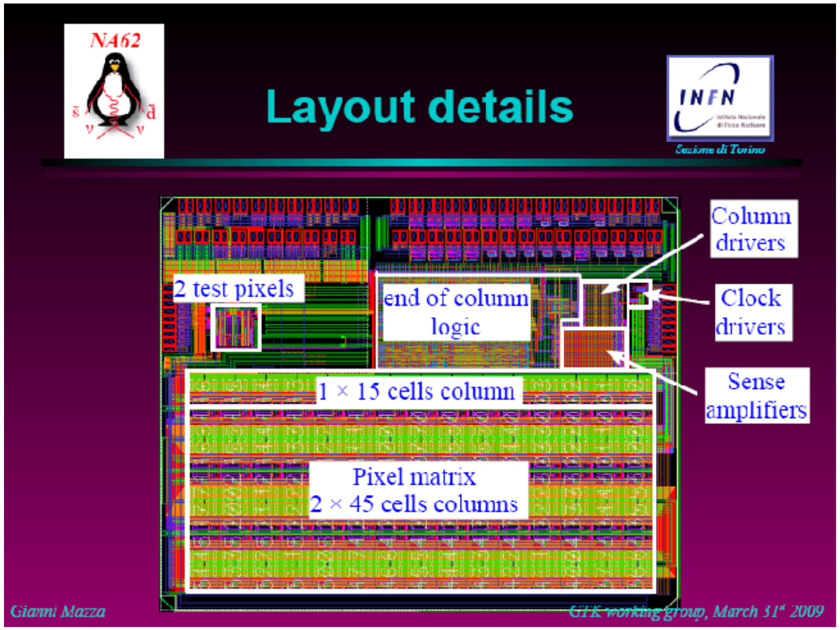
Sensor: 200 μm Si

Pattern: 300 x 300 μm^2

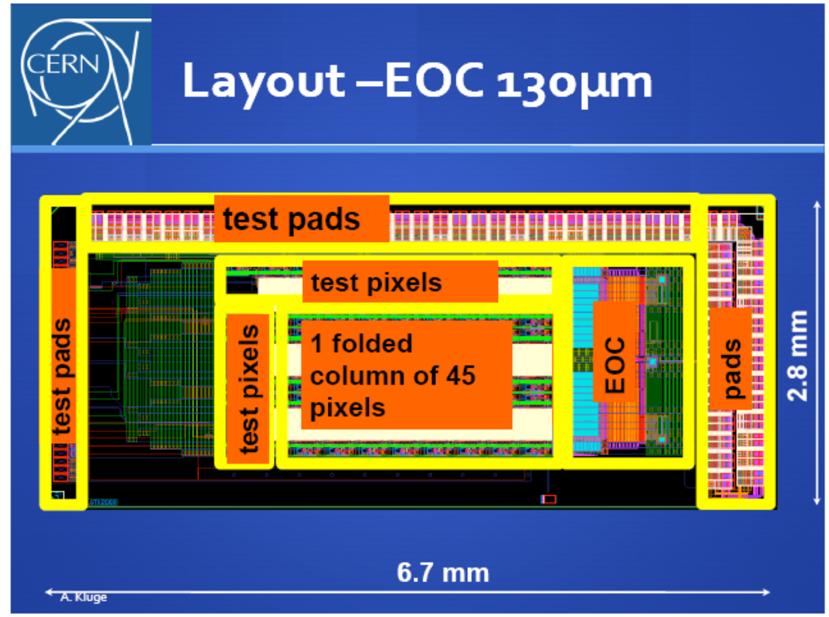
Two options for Read-Out:

- **On-Pixel TDC**
- **End-of-Column TDC**

GTK R/O Prototypes



INFN Design: One TDC / pixel



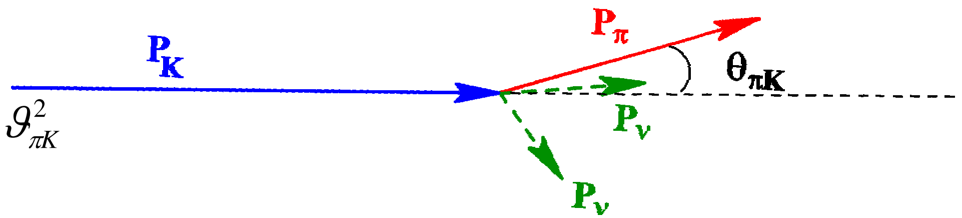
CERN Design: End of Column TDC

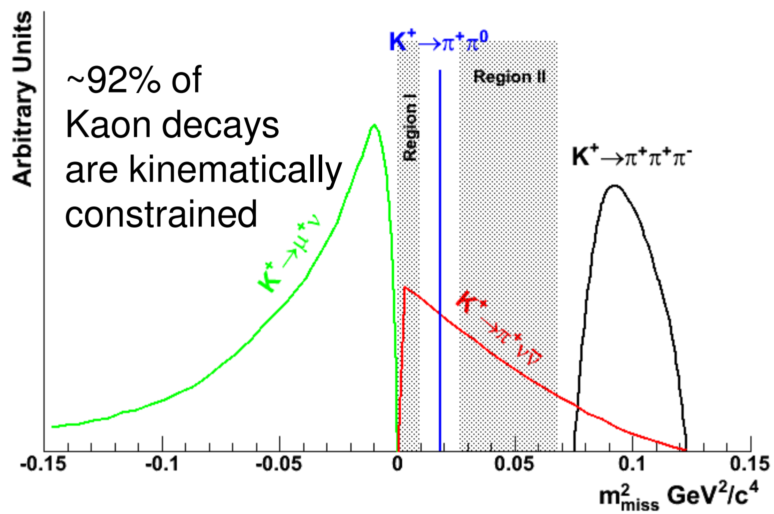
Both Designs in 130 nm IBM CMOS

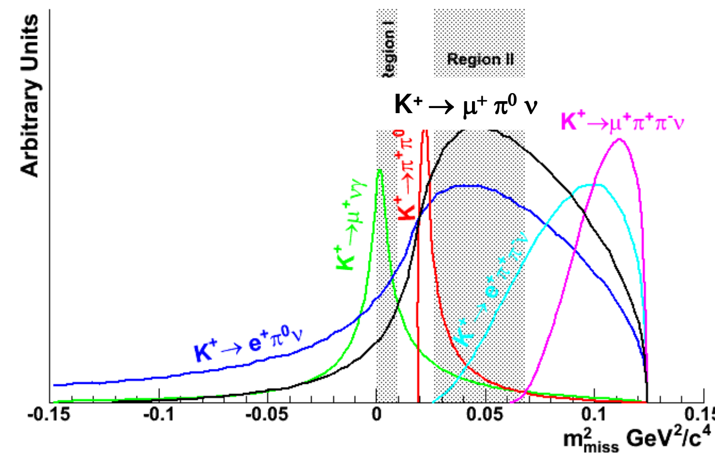
•Prototypes delivered in July, 2009

Background Rejection

$$m^2_{miss} \approx m^2_K\left(1-\frac{|P_\pi|}{|P_K|}\right)+m^2_\pi\left(1-\frac{|P_K|}{|P_\pi|}\right)-|P_K||P_\pi|\vartheta^2_{\pi K}$$

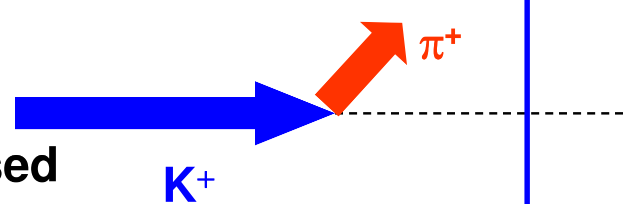






Signature:

- Incoming **high momentum (75 GeV/c) K^+**
- Outgoing **low momentum (< 35 GeV/c) π^+**
- For $K_{\pi 2}$ $P(\pi^0)$ > 40 GeV/c: it can hardly be missed
- PID: CEDAR (π/K), RICH (π/μ), MUV (μ), E/P (e/π)

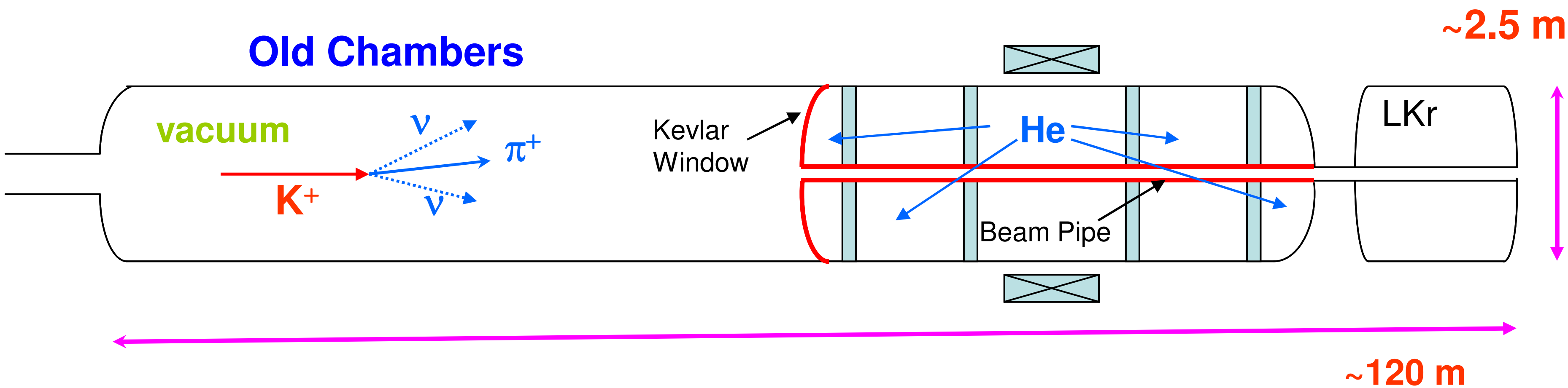


NA62 Sensitivity

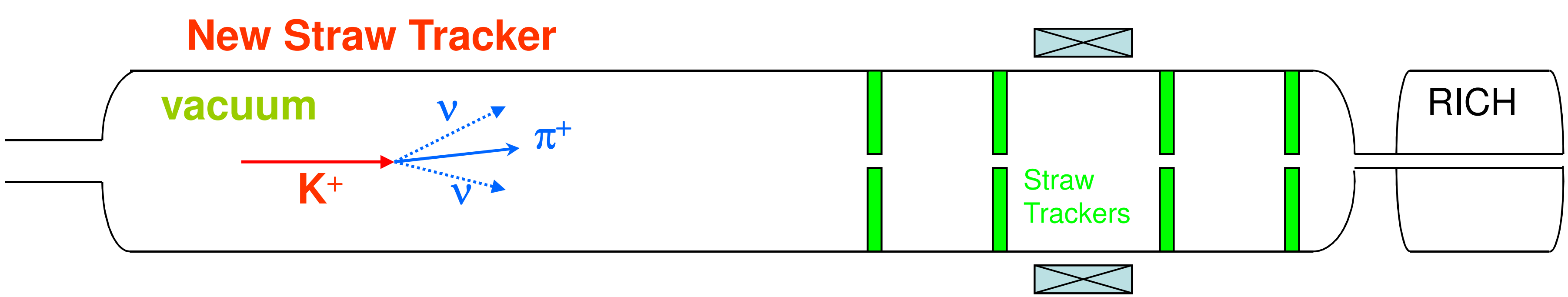
Decay Mode	Events
Signal: $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ *[flux = 4.8×10^{12} decay/year]*	55 *evt/year*
$K^+ \rightarrow \pi^+ \pi^0$ [$\eta_{\pi 0} = 2 \times 10^{-8}$ (3.5×10^{-8})]	4.3% (7.5%)
$K^+ \rightarrow \mu^+ \nu$	2.2%
$K^+ \rightarrow e^+ \pi^+ \pi^- \nu$	≤3%
Other 3 – track decays	≤1.5%
$K^+ \rightarrow \pi^+ \pi^0 \gamma$	~2%
$K^+ \rightarrow \mu^+ \nu \gamma$	~0.7%
$K^+ \rightarrow e^+ (\mu^+) \pi^0 \nu$, others	negligible
Expected background	≤13.5% (≤17%)

Definition of "year" and running efficiencies based on NA48 experience: ~100 days/year; 60% overall efficiency

New Spectrometer

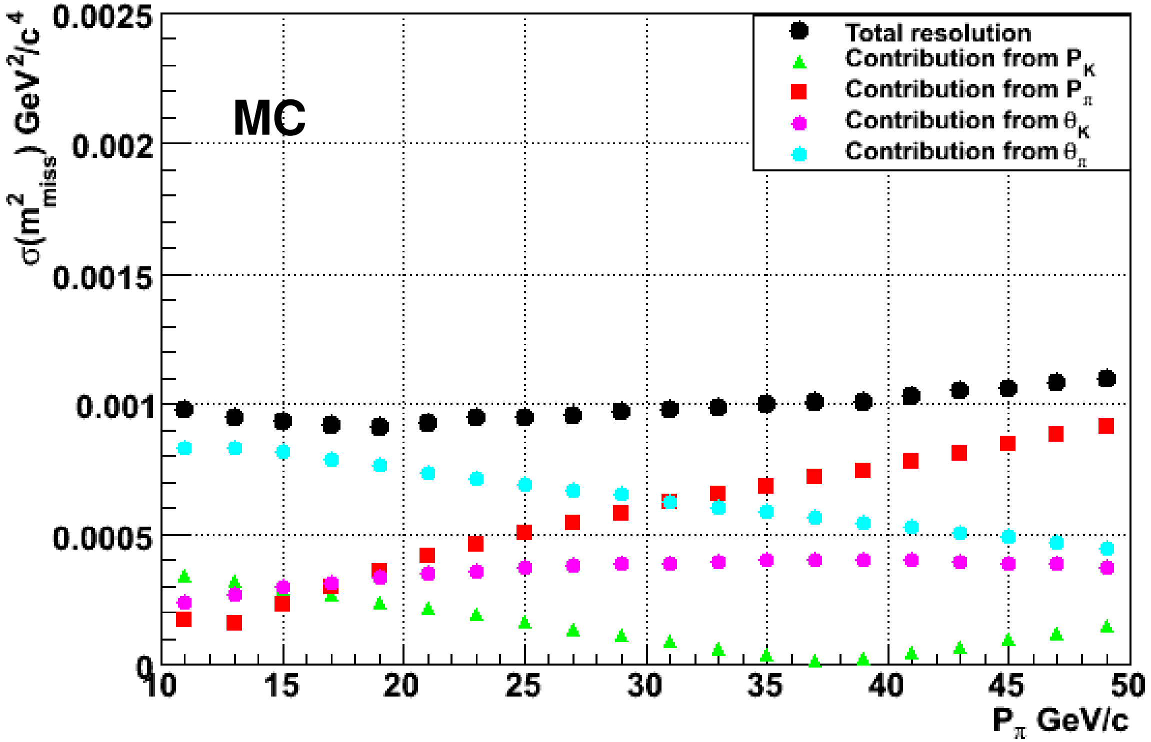


The Straw Trackers operated in vacuum will enable us to:
- **Remove the multiple scattering due to the Kevlar Window**
- **Remove the acceptance limitations due to the beam-pipe**
- **Remove the helium between the chambers**



- **The Straw Tracker is essential to study ultra-rare-decays in flight**

NA62 Kinematic resolution



- Resolutions
  - Gigatracker: $\sigma(P_K)/P_K = 0.2\%$, $\sigma(dX,Y/dZ) \sim 12\ \mu$rad
  - Straw spectrometer: $\sigma(P)/P = 0.3\% \oplus 0.007\%P$, $\sigma(dX,Y/dZ) = 45 \div 15\ \mu$rad

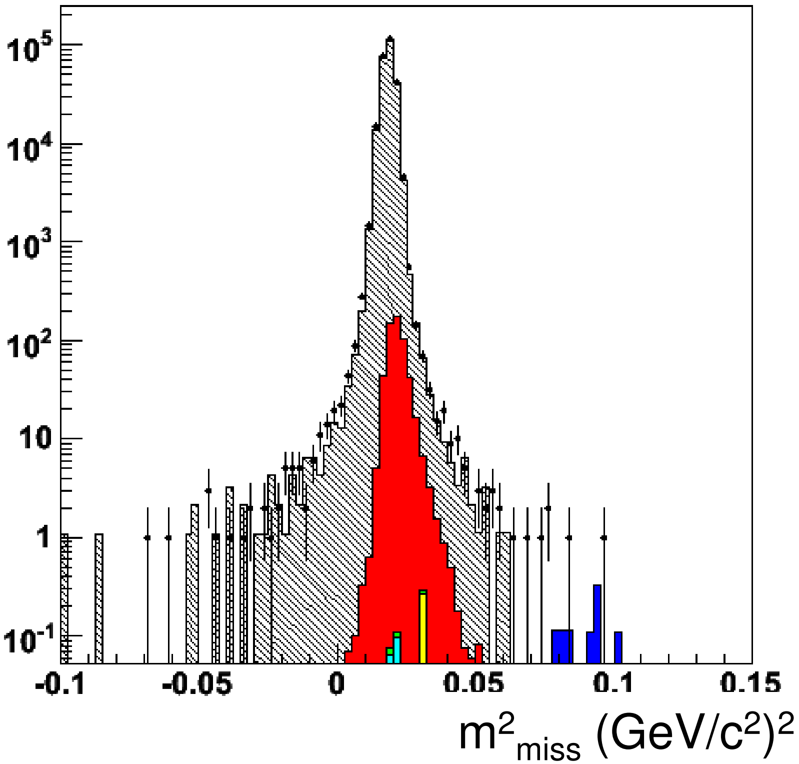
Kinematical Rejection

$K^+ \to \pi^+\pi^0$ selected on 2007 data using LKr information only

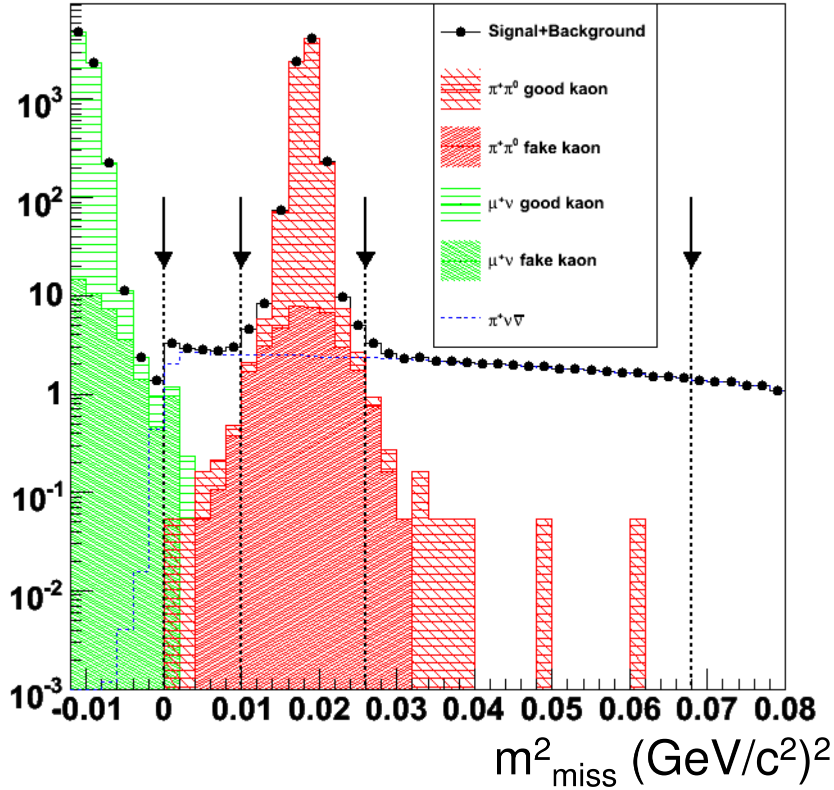
Look at the tails in the m^2_{miss} reconstructed with the NA48 DCH

Data vs. NA48MC: reproducibility of non-gaussian tails within 2x

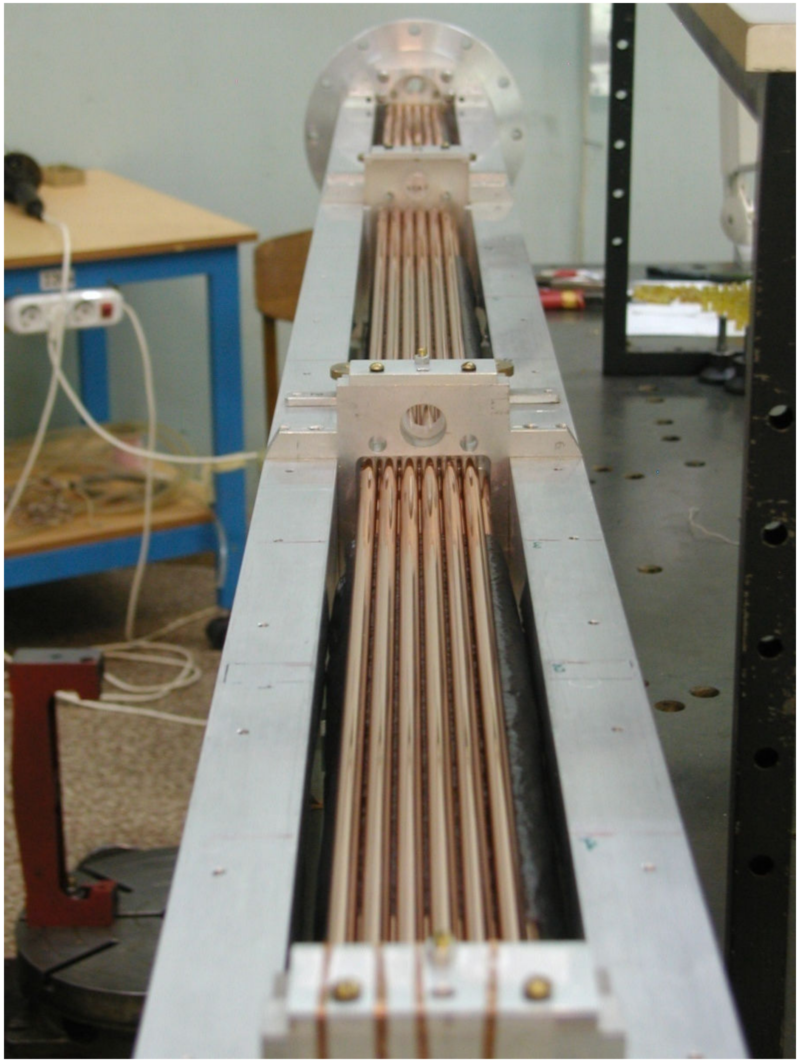
NA48: Data vs. MC



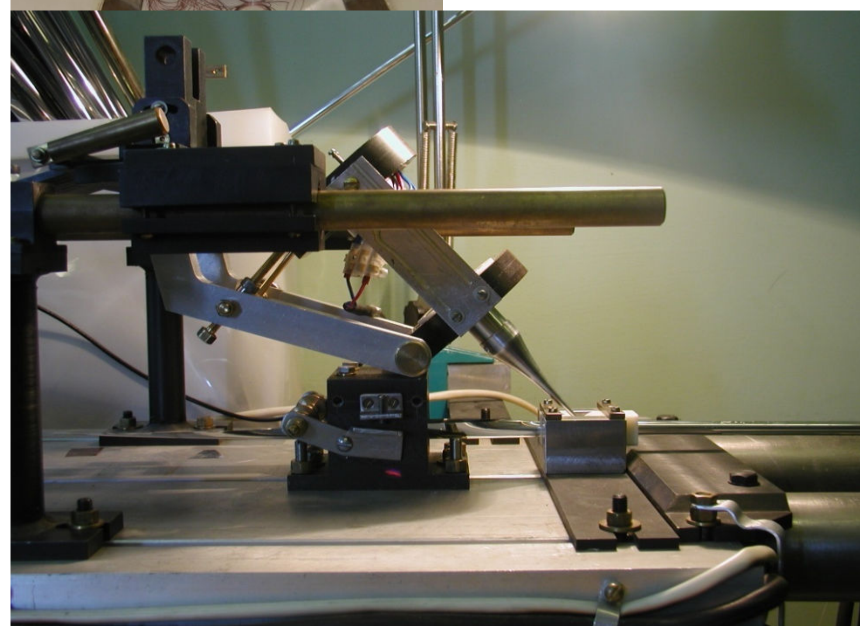
Resolution with STRAW



STRAW Prototype

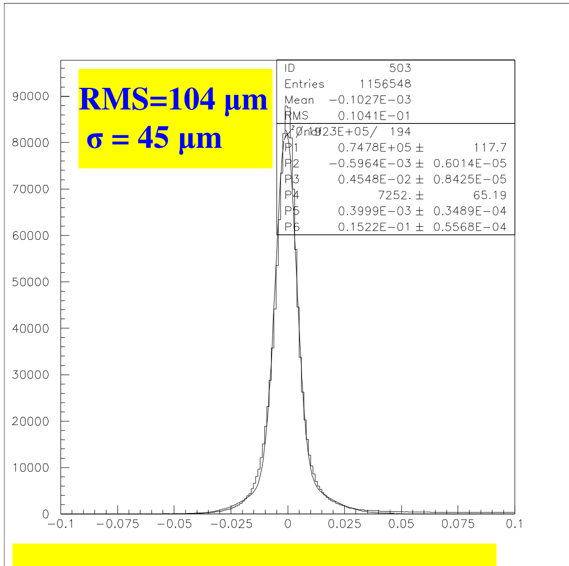


36 μm thick mylar
Ultrasound weld
full length Straw
Prototype: 2.1 m long
Operated in Vacuum

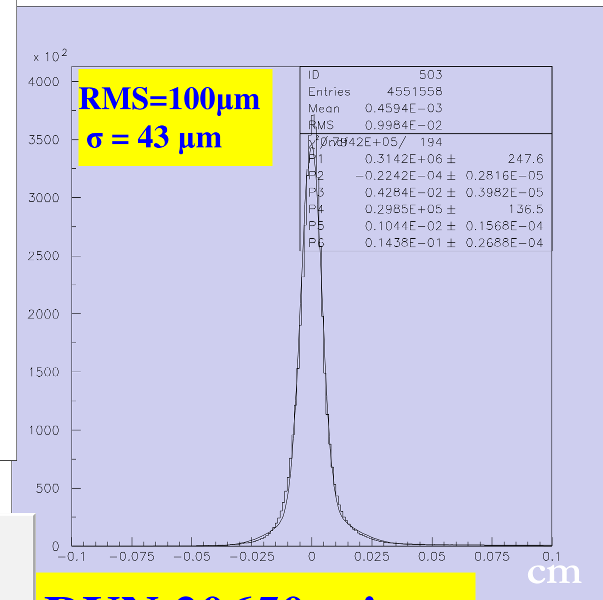


STRAW Prototype: Beam Test

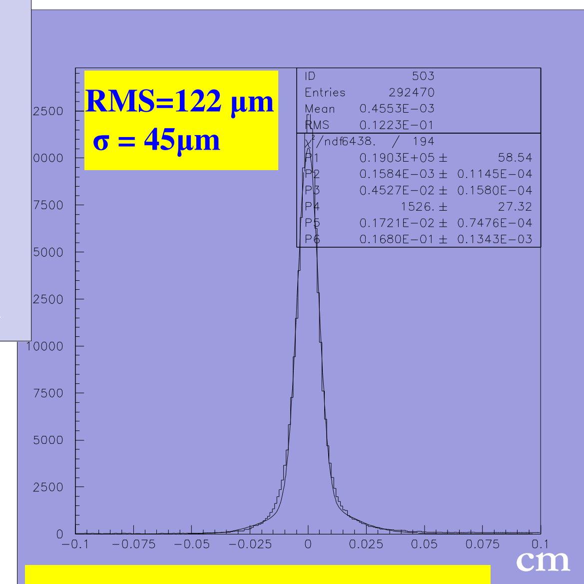
Residuals



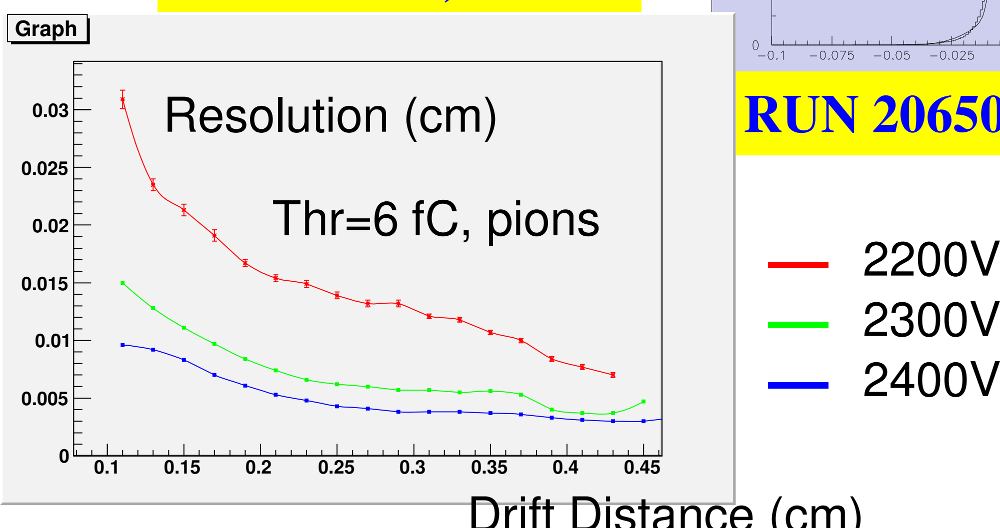
RUN 20629, muons



RUN 20650, pions



RUN 20694, kaons



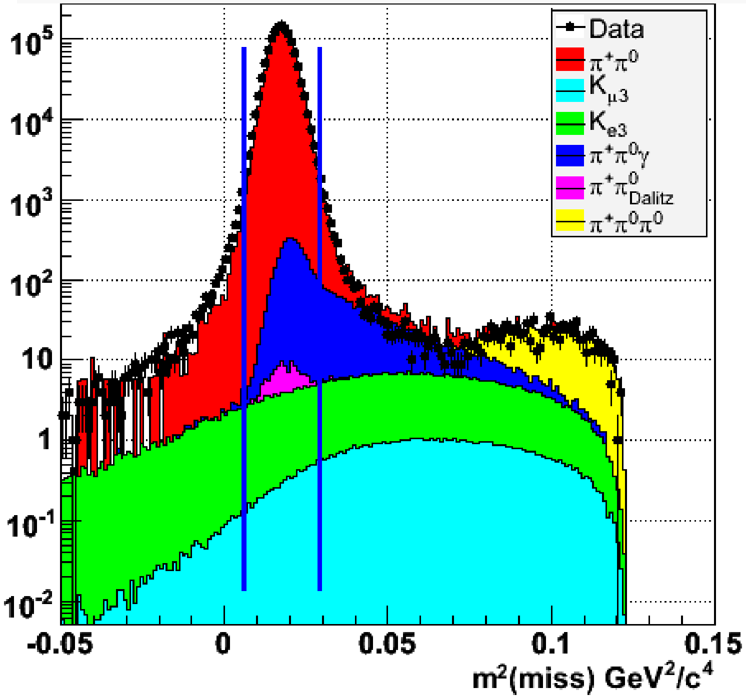
CO_2 (80%) CF_4 (10%) Isob. (10%)

LKr γ Detection Efficiency

LKr ineff. per γ (E_γ > 10 GeV):

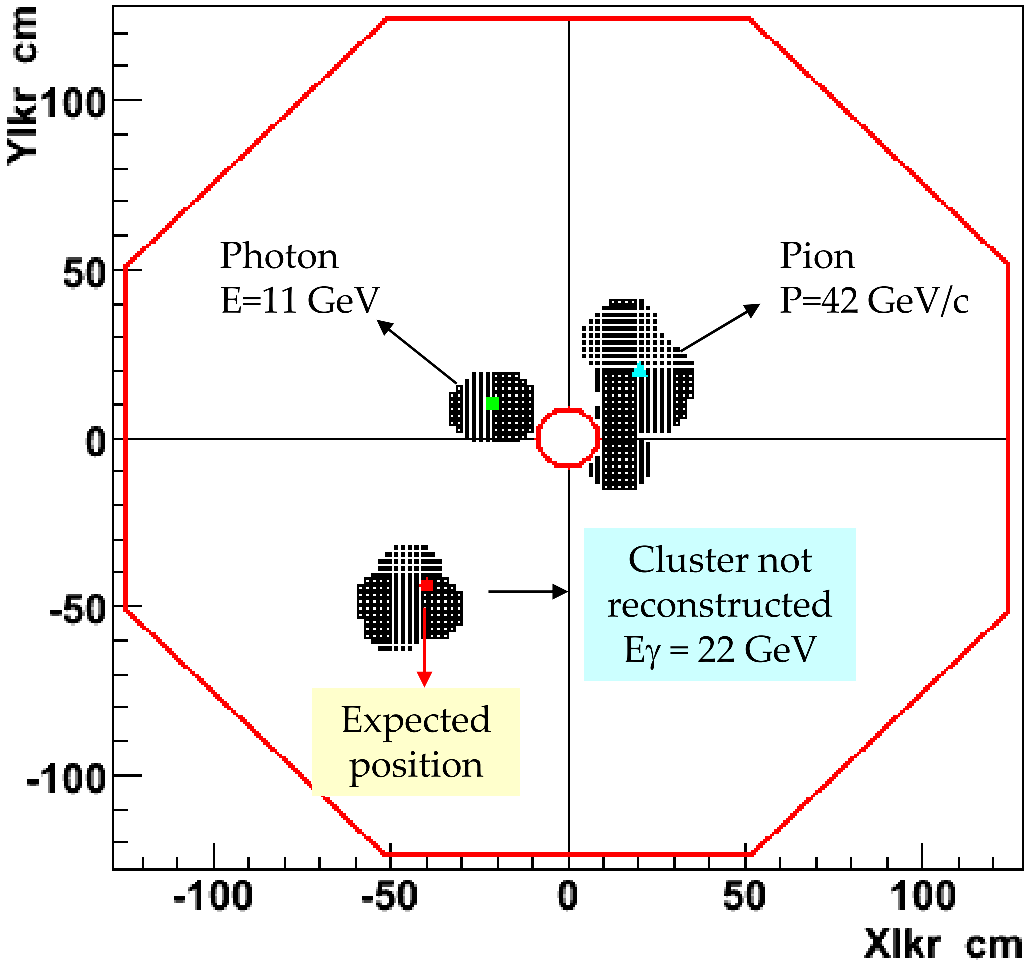
$\eta < 10^{-5}$

$K^+ \to \pi^+ \pi^0$ selected kinematically



Measured from 2004 NA48/2 data

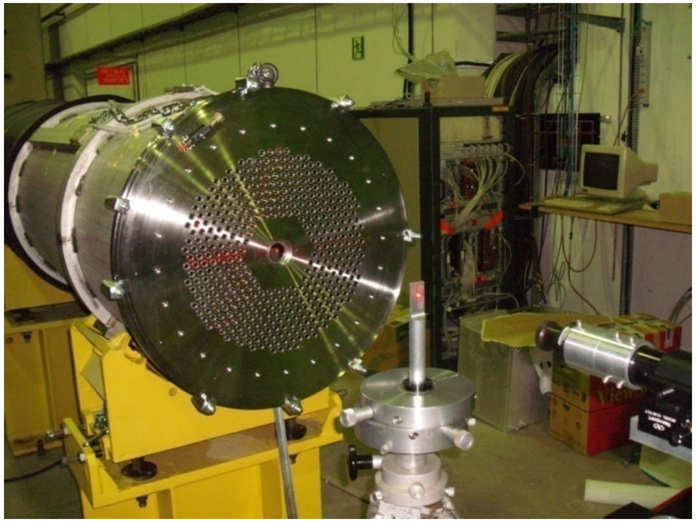
π^+ track and lower energy γ are used to predict the position of the other γ



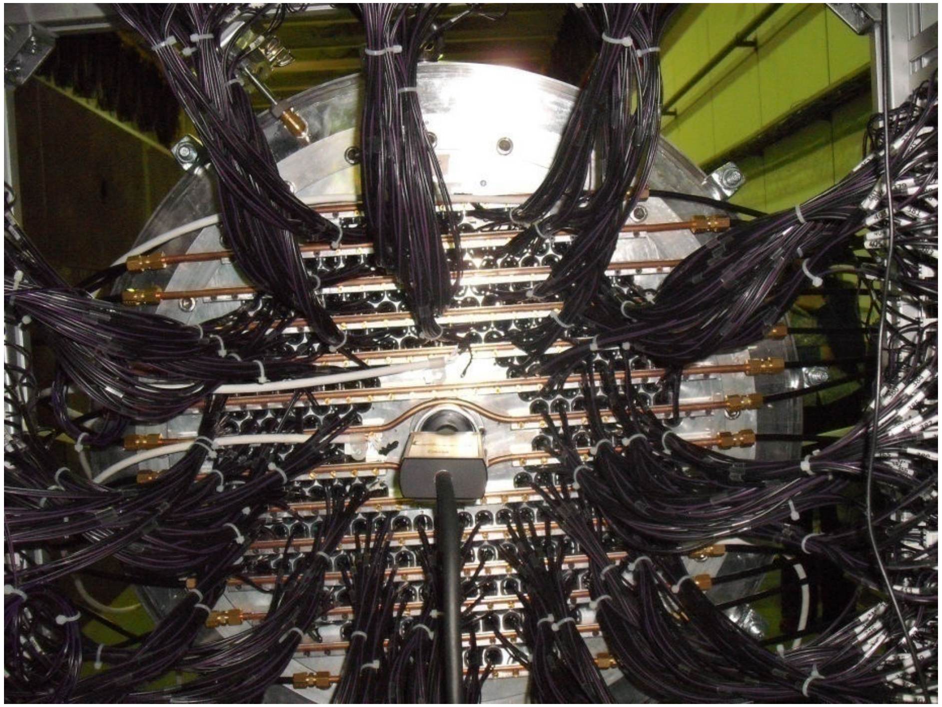
Installation of ANTI-A1

- The first of the twelve Large Angle Vetoes was installed on August 6, 2009
- These lead-glass blocks were formerly used in the OPAL Experiment at LEP

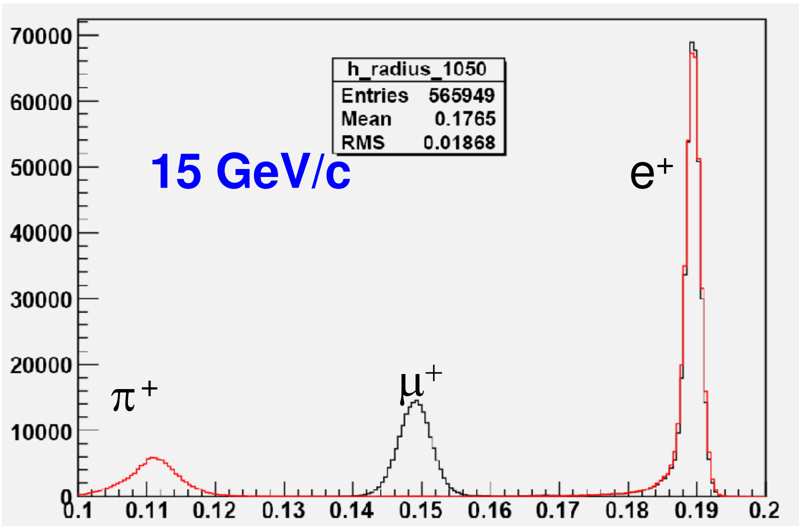
RICH-400 Test beam 2009

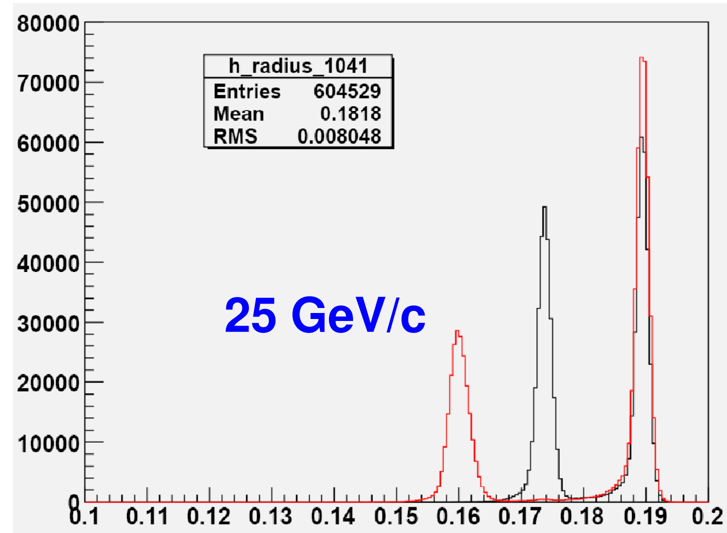


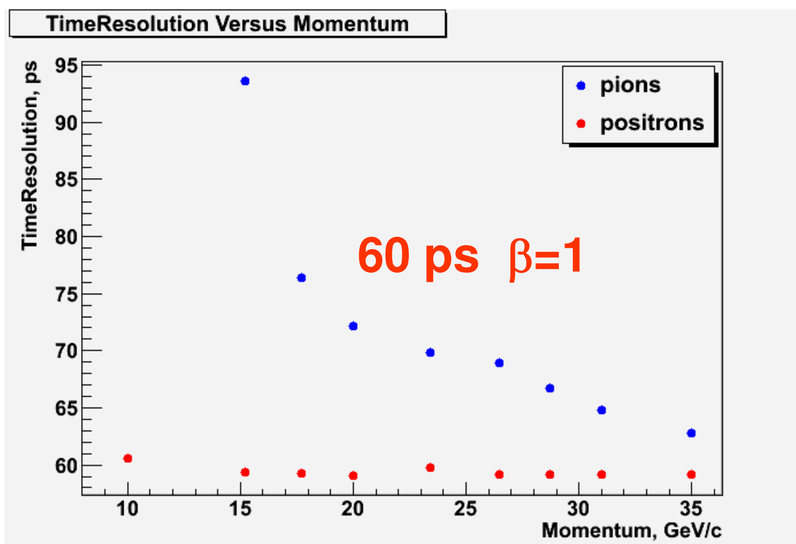
- Full length RICH Prototype
- 400 Hamamatsu R7400 tubes
- 17 m focal length glass mirror
- Pure Neon STP
- Beam tested June 2009



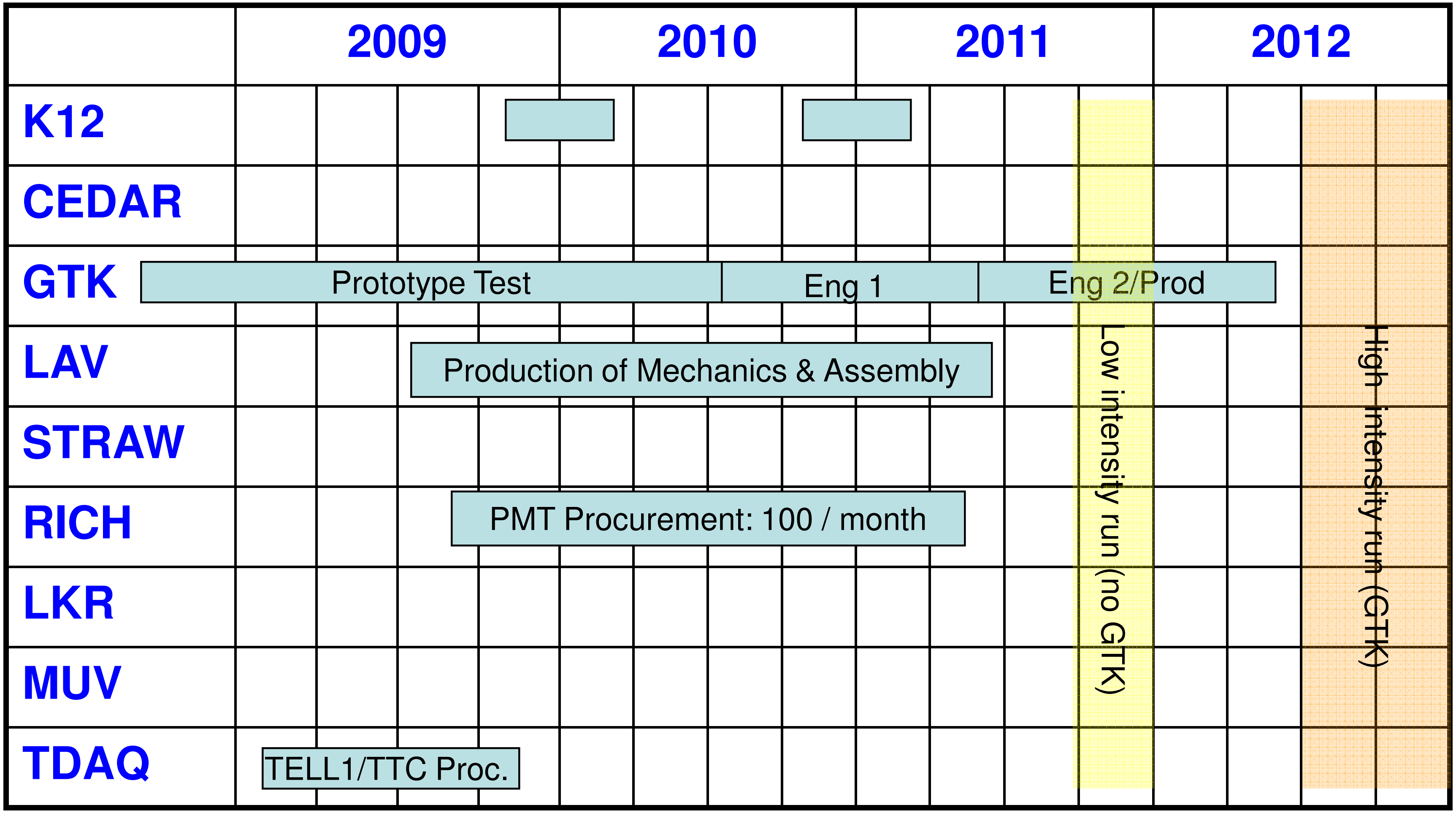
RICH Test, June 2009, Preliminary





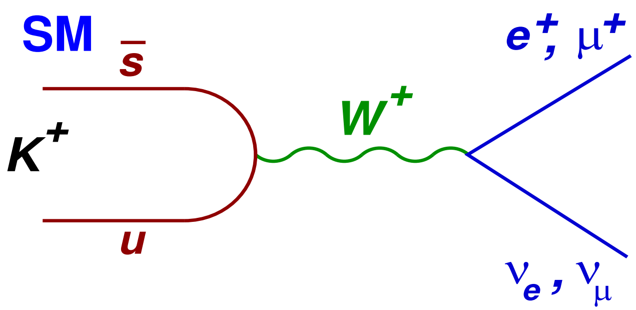


Timescale

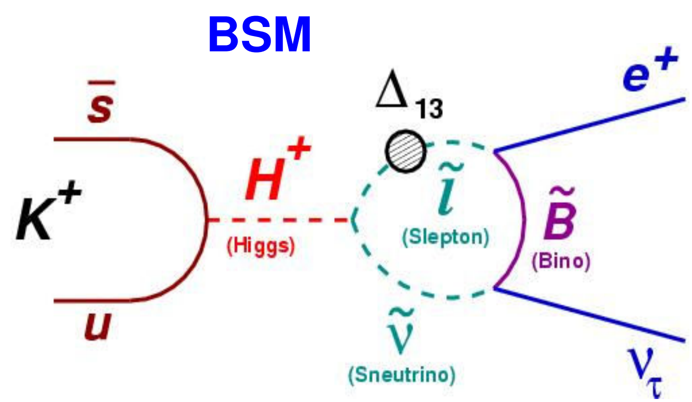

2009
2010
2011
2012
K12
CEDAR
GTK
LAV
STRAW
RICH
LKR
MUV
TDAQ
Prototype Test
Eng 1
Eng 2/Prod
Production of Mechanics & Assembly
PMT Procurement: 100 / month
TELL1/TTC Proc.
Low intensity run (no GTK)
High intensity run (GTK)

R_K: Lepton Universality Test with $K^+ \rightarrow l^+ \nu$ Decays at CERN NA62 First NA62 Result*

New Result presented by Evgueni Goudzovski @ KAON09

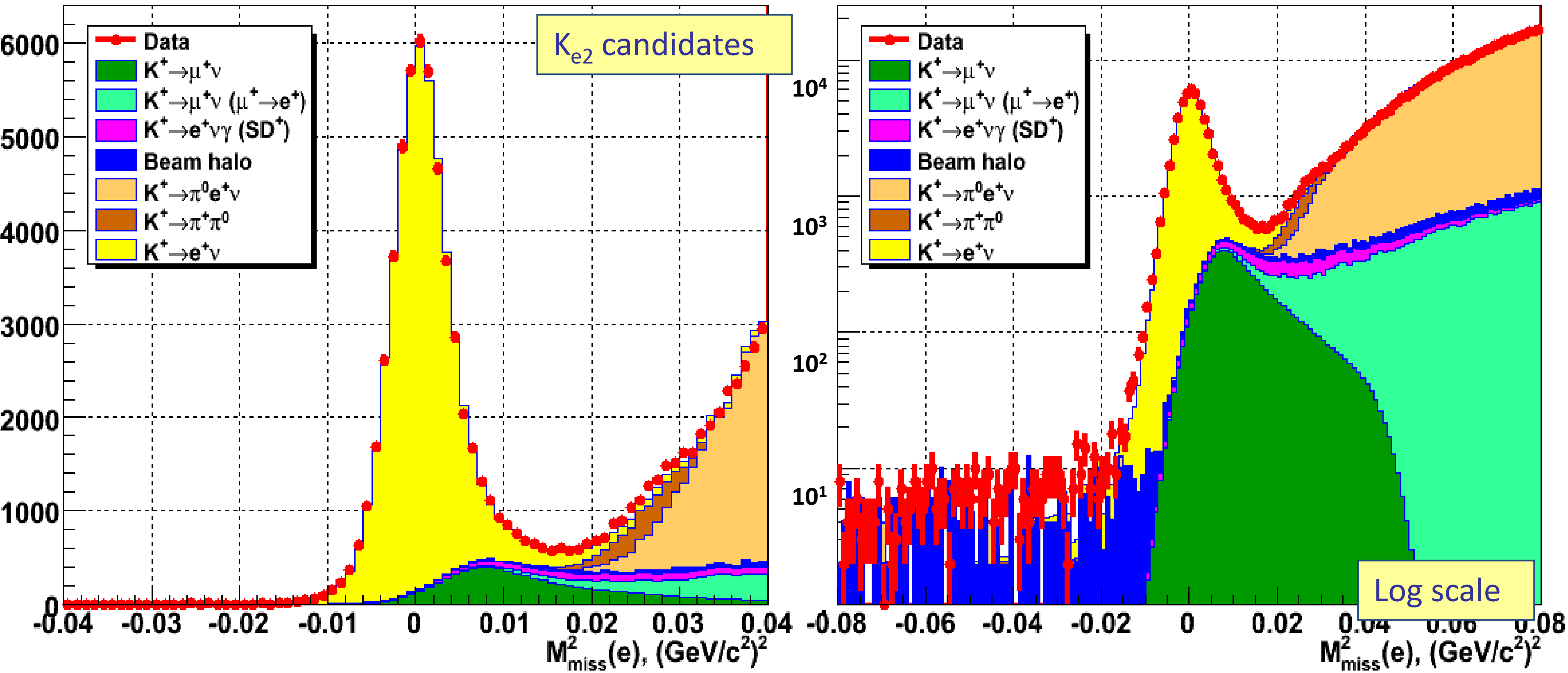


$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot (1 + \delta R_K^{\mathrm{rad.corr.}})$$



* **New Collaboration familiarizing with single-track final states in old setup**

NA62: 40% of 2007 data set



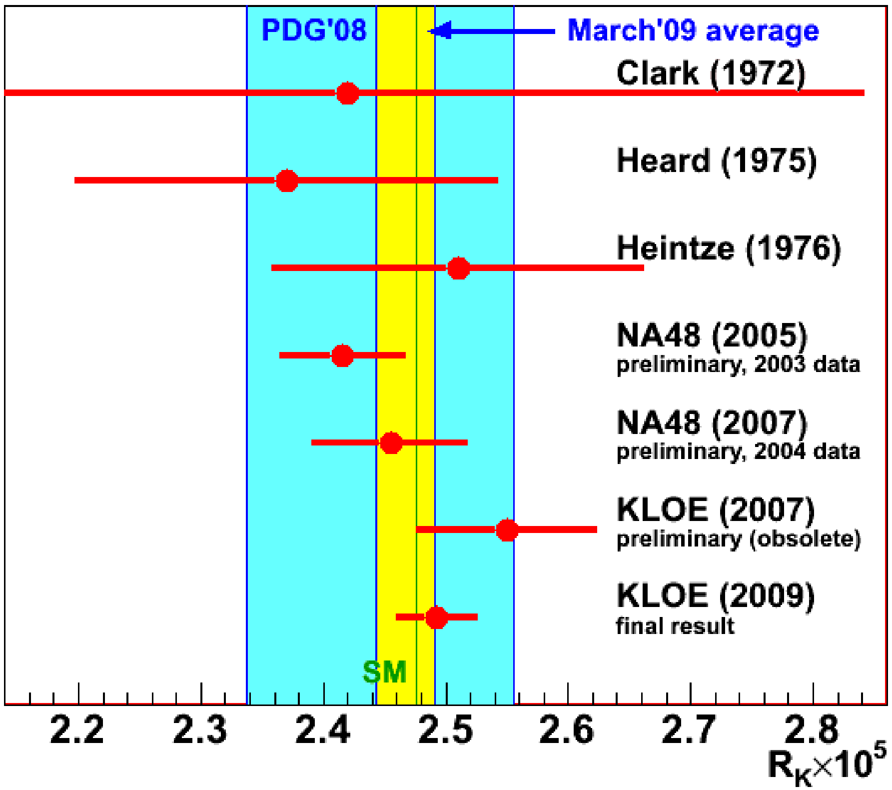
51,089 $K^+ \to e^+ \nu$ candidates,
99.2% electron ID efficiency,
B/(S+B) = (8.0±0.2)%

$R_K = (2.500 \pm 0.012_{stat} \pm 0.011_{syst}) \times 10^{-5}$

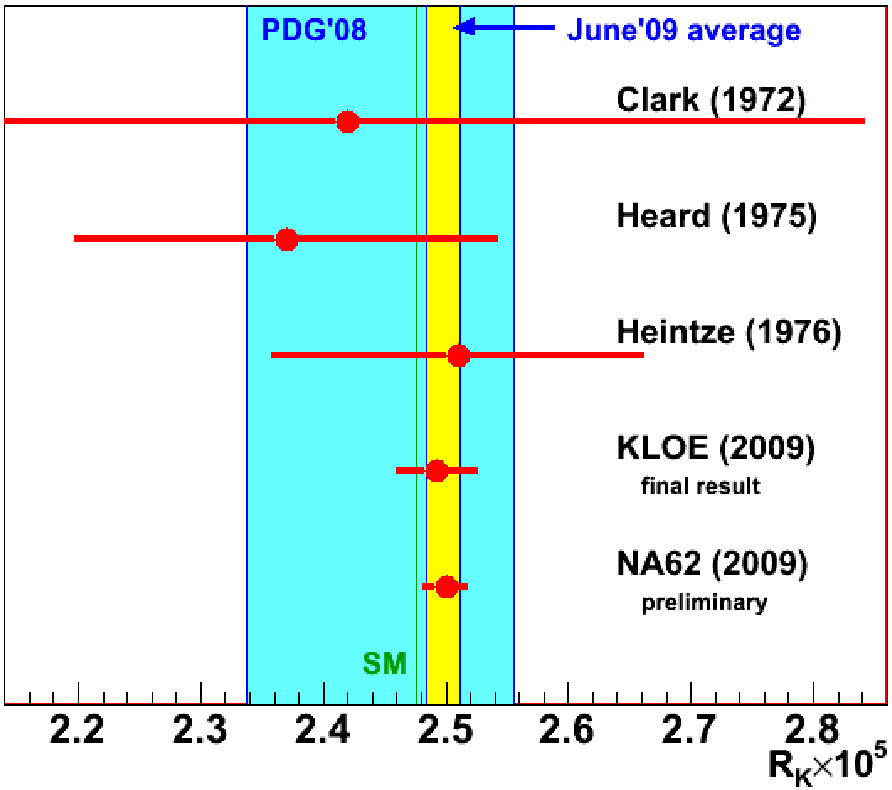
$R_K = (2.500 \pm 0.016) \times 10^{-5}$

Comparison to world data

March 2009



June 2009



World average	$\delta R_K \times 10^5$	Precision
March 2009	2.467 ± 0.024	0.97%
June 2009	2.498 ± 0.014	0.56%

With the full NA62 data sample of 2007/08, the precision is expected to be improved to better than $\delta K_R/R_K = 0.5\%$.

NA62 Status

- New Result R_K=(2.500 ± 0.016) × 10^{-5}. The full 2007-2008 data will allow one to test the SM to < 0.5%
- The $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ proposal was approved by the CERN Research Board (December 5, 2008)
- It is part of the Medium Term Plan (MTP) approved by the CERN Council in June
- With 2 (+1) years of data taking at the SPS, NA62 aims at a ~10% measure of the (SM) $BR(K^+ \rightarrow \pi^+ \nu \bar{\nu})$
- It is compatible with the operation of the LHC
- With ~50 times the kaon flux of NA48/2, the physics menu promises to be rich
- Once the GTK technique is mastered, higher intensities and "factory mode" data taking could be envisaged
- In the longer term (SPS upgrade for sLHC) one looks forward to study also ultra-rare K^0_L decays

Wrap-up

- I hope to have shown that Rare Kaon Decays provide a unique blend of physics reach and advanced experimental technique
- These experiments are perfectly suited for major proton complexes where they can be performed at a small marginal cost
- Some of these measurements are compelling, justifying different experimental techniques
- Given the quality of the theoretical bases, it looks like a perfect experimental game